PROPERTIES OF ABLATION AND INSULATION MATERIALS

Volume I

Thermal Properties of Some Filled and Foamed Low-Density Ablators

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ABSTRACT

Thermal conductivity, thermal expansion and heat capacity were determined on a virgin, low-density, silicone elastomer and a virgin, filled cork, from 150K to 500K. Thermal conductivity and heat capacity were determined on a virgin, high density, silicone phenolic and a virgin, blown (foamed), silicone-elastomer with a carbon black filler in a phenolic-glass honeycomb at about 300K.

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Volume I.

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SUMMARY

Thermal conductivity, enthalpy, thermal expansion and bulk density measurements were made on four virgin ablators. Two silicone-phenolics, MG-36 and E6A7, a filled cork, SLA-561, and a foamed silicone elastomer with a carbon black filler in a phenolic-glass honeycomb, S-20T, were evaluated. For the MG-36 and SLA-561, thermal conductivity, enthalpy (heat capacity) and thermal expansion were measured from 150K to 500K. The thermal conductivity and heat capacity were determined at about 340K for the E6A7 and S-20T.

The E6A7, silicone-phenolic, had a significantly higher bulk density than the other materials and also the highest value of thermal conductivity. Further, the low-density silicone-phenolic, MG-36, and the filled cork, SLA-561, had about the same density and about the same values of thermal conductivity. The blown silicone elastomer, S-20T, had an intermediate value of density and thermal conductivity.

The heat capacities of all four materials were the same within about 11 percent. The filled cork and silicone elastomer had the lowest values of heat capacity.

The MG-36 and SLA-561 both exhibited shrinkages above and below 300K. Permanent shrinkage was also observed after either cooling to 150K or heating to 500K from a reference temperature of about 300K.

Thermal expansion measurements indicated some degree of anisotropy in the MG-36 and SLA-561.

Variabilities between specimens were noted. However, since only duplicate data were obtained and detailed material analyses were not made, the sources of these variabilities have not been defined.

INTRODUCTION

This is the final report to the National Aeronautics and Space Administration, Langley Research Center, for the work on virgin ablative materials under Subtask A of Contract NAS1-7732-1. This work involved the measurement of thermal conductivity, enthalpy (heat capacity) and bulk density of E6A7 and S-20T at 300K and the measurement of thermal conductivity, enthalpy, thermal expansion and bulk density of MG-36 and SLA-561 from 150K to 500K (bulk density at 300K) only). All measurements were made in duplicate.

MATERIALS AND CUTTING PLANS

The materials evaluated in this program were:

1. Low density silicone-phenolic - MG-36
2. Silicone-phenolic - E6A7
3. Filled cork -SLA-561
4. Blown (foamed) silicone-elastomer with carbon black filler in phenolic-glass honeycomb - S-20T

Pictures of the materials are presented in Figure 1 and the compositions are given in Table 1.

The two silicone-phenolics designated MG-36 and E6A7 were fabricated by the NASA Langley Research Center and consist primarily of the same constituents but vary widely in composition. The MG-36 was a low density material and contained significantly more phenolic microballoons and less silicone than the E6A7. The bulk densities of the MG-36 and E6A7 are given in Tables 2 and 3. The MG-36 had a density range from about 0.251 to 0.258 gm/cm^3, whereas, the E6A7 had a density range of from 0.651 to 0.653 gm/cm^3. Of course, molding pressure could also have affected the difference in densities.

The filled cork composition designated SLA-561 was fabricated by the Martin-Marietta Corporation, Denver Division, and consisted of cork particles, fibers and microspheres in a silicone binder. The bulk density of the SLA-561 is given in Table 4. The density of this material ranged from 0.222 to 0.233 gm/cm^3.

The blown (foamed) silicone elastomer designated S-20T was fabricated by the McDonnell-Douglas Astronautics Company - East and consisted of a filled silicone elastomer foamed in a phenolic-glass honeycomb. The honeycomb was probably about 50 percent (by weight) phenolic and 50 percent glass fibers. The nominal

density of the honeycomb was probably about 0.036 gm/cm^3 (2.2 lb/ft^3). The silicone elastomer was highly porous, contained a small percentage of glassy fibers, and was black in color. The black color is believed to arise from a dispersion of carbon black in the silicone resin. The bulk density of the S-20T (given in Table 5) ranged from 0.329 to 0.356 gm/cm^3.

The materials were supplied in bulk form by the NASA Langley Research Center. The cutting plans used to obtain specimens from the bulk materials are presented in Figures 2 through 5. For the low density silicone-phenolic (MG-36), filled cork (SLA-561) and silicone-phenolic (E6A7), it was believed that the properties would be independent of orientation. For these materials, specimens were arbitrarily taken such that the properties were measured in the thickness direction. However, some thermal expansion measurements were also made perpendicular to the thickness direction. Therefore, the thickness direction has arbitrarily been called the X direction and the direction perpendicular to the thickness direction has been defined as the Y direction. When a direction is not spelled out for a particular measurement it is tacit that the measurement is in the thickness or X direction.

APPARATUSES AND PROCEDURES

Thermal Conductivity - ASTM C177 (3 in. Diameter) Guarded Hot Plate

Thermal conductivity measurements were made with the guarded hot plate apparatus described in Appendix A. A schematic of the apparatus is shown in Figure 6. This apparatus requires a specimen 8.25 cm in diameter. For all of the materials evaluated, except the E6A7, the specimen thickness employed was 0.634 cm. For the E6A7, a thickness of 0.952 was used.

The evaluations at cryogenic temperatures were made by flowing either liquid nitrogen or trichlorethelyne chilled with dry ice through the cold plate (see Figure 6). When performing the measurements at temperatures below room temperature the apparatus was heavily insulated with Fiberfrax^R blanket and was run in an atmospheric air environment.

Enthalpy (Heat Capacity) - Adiabatic Calorimeter

Enthalpy measurements were made with the adiabatic calorimeter described in Appendix B. For the evaluations at cryogenic temperatures, the cold box described in Appendix B was used to cool the specimen. When the cold box was used, a dry nitrogen purge system was used to keep moisture from the system. Also,

a sweep purge was used across the outlet of the cold box during the drop to keep cold vapors from penetrating to the drop cup.

Enthalpy measurements are experimentally referenced to the final temperature of the calibrated cup into which the specimen is dropped. These values are then referenced to a common temperature of 303K (temperature near that at which cup normally equilibrates). The referencing is performed from a linear extrapolation of the data with the equation

$$h_{303} = h \left(\frac{t_s - 303}{t_s - t_c} \right) \qquad (1)$$

h_{303} = enthalpy referenced to 303K
h = measured enthalpy referenced to t_c
t_s = specimen temperature - K
t_c = final temperature of drop cup - K

The enthalpy values which are referenced to 303K are then normally referenced to 273K (ice point) by the following method. A smooth curve is drawn through the data points which are referenced to 303K and the value of enthalpy (negative) at 273K is read from the curve. This value is then added (without sign) to all enthalpy values to reference the values to 273K.

Heat capacity is derived from the slope of the enthalpy temperature curve. Two methods of determining heat capacity are used. The graphical method is to read curve values at about 50K on either side of a given mean temperature and divide the difference in enthalpy by the temperature interval. The analytical method is to fit an equation of the following form to the data by the method of least squares:

$$h_{273} = aT + bT^2 + cT^{-1} + d \qquad (2)$$

The heat capacity is obtained from the derivative of the enthalpy equation

$$HC = a + 2bT - c^*T^{-2} \qquad (3)$$

Notice that c* is used instead of c in Equation 3. The constant c* is obtained by forcing the heat capacity calculated from Equation 3 to agree with a graphically determined value at some predetermined temperature level. This technique

is similar to that of Kelley (see Reference 1 in Appendix B) in forcing the heat capacity through a known value.

In performing the enthalpy measurement, specimens were dropped at progressively higher temperatures. Drops at cryogenic temperatures were made first and then the drops progressed up the temperature scale. This insured that changes in the material as a function of temperature did not influence the values at lower temperatures.

Thermal Expansion - Quartz Dilatometer

Thermal expansion measurements were made with the quartz tube dilatometer described in Appendix C. This apparatus employs a hollow quartz tube and a quartz pushrod. The pushrod bears on the top of a specimen centered in the tube and transmits the differential expansion to a dial gage. The sensitivity of the dial gage is ±0.0001 inch.

For the evaluations at cryogenic temperatures, a cooling coil was used to control the specimen temperature. The cooling coil was spiral shaped and contained numerous jets through which liquid nitrogen vapor flowed and impinged upon the quartz tube. Temperatures were controlled by controlling the flow of liquid nitrogen.

The apparatus was proven at cryogenic temperatures from evaluations of a copper standard supplied by NBS. Our measurements agreed within 0.1×10^{-3} in./in. with the curve supplied by NBS.

In performing the evaluations, the specimen was first cooled to about 150K. Then, data were obtained upon heating to successively higher temperatures. In some cases, the expansion curve did not go through zero at 300K (initial reference temperature). The value obtained at 300K after cooling to 150K was taken as the zero reference for further data obtained to 500K.

The thermal expansion specimens were about 7.62 cm long by 1.27 cm diameter. A spherical radius of 7.62 cm was machined on either end.

Bulk Density

Bulk density was determined from measurements of specimen dimensions and weight. The volume was calculated from the dimensions and divided into the measured weight to determine bulk density. Dimensions were measured with a micrometer and weight was measured with an analytical balance to the nearest 0.0001 gram.

DATA AND RESULTS

Thermal Conductivity

MG-36. - The thermal conductivity data for the MG-36 are presented in Figure 7 and in Table 6. This material exhibited an increase in thermal conductivity from about 0.038 W/m-K at 150K to 0.061 W/m-K at 350K and then a slight decrease to about 0.057 W/m-K at 500K. Above 200K there was a difference in the thermal conductivities of the two specimens evaluated of about 8 percent.

SLA-561. - The thermal conductivity data for the SLA-561 are presented in Figure 8 and in Tables 7 and 8. The thermal conductivity increased from about 0.038 W/m-K at 150K to 0.06 W/m-K at 500K.

E6A7. - The thermal conductivity data for E6A7 at about 345K are presented in Table 9. A thermal conductivity of 0.105 W/m-K was measured for both specimens.

S-20T. - The thermal conductivity data for the S-20T at about 340K are presented in Figure 9 and in Table 10. The thermal conductivity of this material was about 0.078 W/m-K.

Enthalpy (Heat Capacity)

MG-36. The enthalpy values measured on the MG-36 are presented in Figure 10 and in Table 11. The enthalpy increased smoothly from about -1.15×10^5 J/Kg at 180K to 4.2×10^5 J/Kg at 540K. At temperatures of about 450K some specimens began to smoke and behave erratically. Hence, this temperature represents the temperature at which degradation of the material begins. This degradation was evidenced by weight losses of up to about 10 percent.

The values of heat capacity derived from the enthalpy data are presented in the upper portion of Figure 10. The heat capacity exhibited a typical increase from about 1050 J/Kg-K at 200K to 1700 J/Kg-K at 500K. The heat capacity values should not be considered meaningful above about 400K because of the degradation.

SLA-561. - The enthalpy data for the SLA-561, filled cork, are presented in Figure 11 and in Table 12. The enthalpy curve exhibited a smooth increase from -1.20×10^5 J/Kg at 150K to 3.38×10^5 J/Kg at 500K.

The heat capacity values for the SLA-561 are presented in the upper portion of Figure 11. There was good agreement between the graphical and analytical values of heat capacity. The heat capacity increased from about 950 J/Kg-K at 200K to 1700 J/Kg-K at 500K.

E6A7. - The enthalpy data for the E6A7 are presented in Figure 12 and in Table 13. These measurements were intended only to provide a value for the heat capacity in the vicinity of 300K.

The heat capacity of the material is given in the upper portion of Figure 12. The heat capacity of the E6A7 was 1440 J/Kg-K at 300K.

S-20T. - The enthalpy data for the S-20T are presented in Figure 13 and in Table 14. Again, the purpose of these enthalpy measurements was to define the heat capacity at 300K.

The heat capacity of the S-20T is presented in the upper portion of Figure 13. The heat capacity at 300K was 1350 J/Kg-K.

Thermal Expansion

MG-36. - The thermal expansion data for the MG-36 are presented in Figures 14 and 15 and in Tables 15 and 16. Shown in Figure 14 is the expansion in the X direction. The MG-36 exhibited only a slight positive expansion at about 340K of 0.5×10^{-3} cm/cm. Above and below this temperature the material exhibited a shrinkage. The shrinkage was about -7×10^{-3} cm/cm at 150K and -17.5×10^{-3} cm/cm at 500K.

Data for the expansion of the MG-36 in the Y direction are presented in Figure 15. In the Y direction, the MG-36 exhibited less shrinkage above 350K (-12.5×10^{-3} cm/cm at 500K) but had the same character as the shrinkage in the X direction.

SLA-561. - The thermal expansion data for the SLA-561, filled cork, are presented in Figures 16 and 17 and in Tables 17 through 20. In the X direction (see Figure 16), the SLA-561 exhibited a shrinkage above and below 300K. The shrinkage was -7.1×10^{-3} cm/cm at 150K and about -4×10^{-3} cm/cm at 400K. Between 400 and 500K the material exhibited either a zero or slightly positive coefficient of thermal expansion; however, the total expansion remained negative.

One thermal expansion evaluation was made in the Y direction on the SLA-561 (see Figure 17). In the Y direction, the material did not show the same shrinkage as in the X direction but exhibited negligible change in length to about 480K with a shrinkage above this temperature of about -1.3×10^{-3} cm/cm at 530K.

DISCUSSION

The bulk densities, thermal conductivities and heat capacities at about 300K for the four materials are summarized in Table 21. Also shown in Table 21 are calculated values of thermal diffusivity.

Note in Table 21, that the highest density material, E6A7, had the highest value of thermal conductivity; and the lowest density material, SLA-561, had the lowest value of thermal conductivity. This suggested that for the compositions studied, thermal conductivities were primarily a function of density. Hence, a plot of thermal conductivity versus density was made by overplotting the data for several different materials. These data are presented in Figure 18 and data for three other virgin ablation materials (reported in Volume III) were also included in the plot. The data plot showed a reasonably strong correlation with bulk density. Since the measurements were made in air a line was drawn through the value for the thermal conductivity of air at zero density (100 percent porosity).

The correlation between thermal conductivity and bulk density does not infer that the thermal conductivity is not influenced by composition; however, it does make it appear that there is enough similarity between the properties of the constituents used in these materials (and the structures) that density (porosity) has a large effect. The slope of the curve has not been analytically determined and it is probable that the departures from the curve and the slope of the curve are related to composition. A more detailed analysis would be required to analytically resolve the behavior noted.

Thermal diffusivity is important for understanding heat transfer in transient situations. From the standpoint of thermal diffusivity,the E6A7 (highest density) had the lowest value of thermal diffusivity of 1.12 x 10^{-3} cm^2/sec. The silicone-elastomer and silicone-phenolic had about the same thermal diffusivities with values of 1.72 x 10^{-3} cm^2/sec and 1.67 x 10^{-3} cm^2/sec, respectively. The lowest density material, filled cork, had the highest thermal diffusivity value of 2.01 x 10^{-3} cm^2/sec. However, from a thermal protection standpoint, a low value of thermal diffusivity of the virgin material alone does not mean that a material is a good ablator. There are tradeoffs involved between weight, gas evolution and char thermal conductivity under quasi-steady ablation conditions.

The heat capacities of the S-20T, silicone elastomer and the SLA-561, filled cork, were about the same with values of 1330 and 1290 J/Kg-K, respectively. The two silicone-phenolics, E6A7 and MG-36, had heat capacities of 1440 and 1420 J/Kg-K, respectively. The MG-36 exhibited signs of degradation at about 450K which was reflected in erratic enthalpy data at this temperature. Some of the specimens of MG-36 smoked upon being dropped from the furnace indicating a change in structure. Hence, the heat capacity of the MG-36 is defined only to about 400K.

The MG-36 and SLA-561 showed about the same level of shrinkage at cryogenic temperatures (-7 x 10^{-3} cm/cm at 150K). However, they exhibited somewhat different behaviors above 300K. The MG-36 reached a peak expansion at 330K and then a continuous shrinkage to a value of about -17.5 x 10^{-3} cm/cm at 500K. The SLA-561 began shrinking at about 300K and showed a leveling off at about 400K to a value of about -4 x 10^{-3} cm/cm. Two of three specimens of SLA-561 evaluated, increased in expansion between 400 and 500K and one exhibited a continuous decrease.

For the MG-36, the thermal expansions in the X and Y directions had similar characters but there was less shrinkage observed in the Y direction (-12.5 x 10^{-3} cm/cm at 500K compared to -17.5 x 10^{-3} cm/cm). For the SLA-561, the expansion was also less in the Y direction with a value of zero at 480K as compared to values in the X direction ranging from -3 x 10^{-3} to -4.3 x 10^{-3} cm/cm. Hence, neither material was totally isotropic in thermal expansion.

Both the MG-36 and SLA-561 exhibited rather large values of permanent shrinkage after heating to 500K. These permanent

shrinkages are summarized below:

MG-36

X Direction	-11.4×10^{-3} cm/cm
	-23.2×10^{-3} cm/cm
Y Direction	-23.5×10^{-3} cm/cm

SLA-561

X Direction	-7.3×10^{-3} cm/cm
	-13.5×10^{-3} cm/cm
	-20.9×10^{-3} cm/cm
Y Direction	-8.6×10^{-3} cm/cm

As can be seen, these values of permanent shrinkage are significant.

A permanent shrinkage was also observed after cooling to 150K and heating to 300K. However, these shrinkages were in all cases much lower than the shrinkages observed after heating to 500K. The MG-36 exhibited permanent shrinkages after cooling to 150K of from -0.15×10^{-3} to -0.43×10^{-3} cm/cm and the SLA-561 showed shrinkages of -1.11×10^{-3} and -1.30×10^{-3} cm/cm.

CONCLUDING REMARKS

The thermal conductivity, heat capacity and thermal expansion of a low-density silicone-phenolic, MG-36, and a filled cork, SLA-561, were determined from 150K to 500K. Thermal conductivity and heat capacity were determined at about 340K for a silicone-phenolic, E6A7, and a blown silicone elastomer in a phenolic-glass honeycomb, S-20T.

The thermal conductivities of the MG-36 and SLA-561 increased from 150K to about 300K and then tended to level between 300K and 500K.

At 340K, the thermal conductivities of all four materials tended to follow nearly linearly the density differences in the materials. This variation with density appeared to be somewhat independent of composition (surely not completely independent). The highest density material, E6A7, had a thermal conductivity of 0.105 W/m-K at 340K and the lowest density material, SLA-561,

had the lowest value of thermal conductivity of about 0.059 W/m-K at this same temperature.

Both silicone-phenolics had about the same values of heat capacity at 340K of about 1430 J/Kg-K. The silicone elastomer and filled cork had lower heat capacities than the silicone-phenolics, 1330 J/Kg-K and 1290 J/Kg-K, respectively.

The MG-36 and SLA-561 both exhibited negligible expansions and shrunk at temperatures below and above the reference temperature of about 300K. Both materials exhibited permanent shrinkages after cooling to 150K and after heating to 500K. The shrinkages which occurred after cooling were significantly less than those which occurred after heating.

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APPENDIX A

THERMAL CONDUCTIVITY TO 1000°F

Apparatus and Procedure

Thermal conductivity runs can be made with any of the three guarded hot plate apparatuses, which are slightly modified from the standard ASTM C177-45 design. All three are identical in operating procedure and design except in size and are classified as either the 14", 7", or 3" apparatus depending on the diameter of the specimen used. Specimen thicknesses are from 1/8" to 3" and should be about 1/2" for nominal values of 3 Btu in./hr ft^2°F. Duplicate specimens are required per run. Figures 1 and 2 are photographs showing the three apparatuses.

The apparatus consists of a central heater plate surrounded by a guard heater, each separately controlled. The guard ring is maintained at the same temperature as the central heater so that all of the heat flow is normal to the specimen surfaces. The temperature differences between the guard and central sections are measured by means of differential-thermocouple junctions connected in series. The 14" and 7" apparatuses contain eight differential junctions, whereas the 3" apparatus contains four. The heater plate is sandwiched between layers of filler material, the hot-face thermocouples, the specimen, cold-face thermocouples, filler material, a copper plate, and finally a cold source to dissipate the heat. The cold source consists of a copper coil enclosed in an aluminum box on the 14" apparatus, a copper coil soldered to a copper plate on the 7" apparatus, and a spiral baffled copper container on the 3" apparatus. In addition to the thermocouples in contact with the specimen, thermocouples are located in the central heater and the outer copper cold plates.

To provide intimate contact at all interfaces, the entire sandwich assembly is pressed firmly together with the total load application desired, which is usually 600 pounds. This is accomplished by spring loading and edge clamps on the 14" rig, central screw loading and edge clamps on the 7" rig, and a screw loaded frame on the 3" apparatus.

For the determinations between -50°F to 150°F, a filler material of gum rubber is used. From 150°F to 1000°F Fiberfrax paper is used as a filler. The overlapping data at 150°F provides a check on any possible uncertainty due to poor intimate contact resulting from either specimen or filler surface irregularities. If the data agree within approximately 5%, the run is continued; however, if the agreement is not within 5%, the thermocouples are replaced, the specimen is removed, surfaces are resanded, and the run is repeated.

The thermocouples used on the hot and cold side of the specimen are made from 0.005" diameter Chromel/Alumel wire electrically insulated with 0.003" teflon tape. The junction is made by soldering the wires to a small square of 0.002" thick brass shim stock called a "getter". The teflon insulated leads are sandwiched between the specimen and filler material to assure isothermal conditions along the length of the wire. This arrangement insures that there is no air film between the specimen and the thermocouples, and that good, intimate contact exists at all interfaces.

Single thermocouples in the center of the heater plate and cold plate monitor the temperatures of the heater and cold plates in order to obtain the over-all temperature drop through the assembly.

The assembly is arranged to operate with the specimen placed in the apparatus horizontally, as shown in Figures 1 and 2. The specimens required are flat panels sized to fit the apparatus. The assembly is insulated around the edges by either Fiberfrax or glass wool batt.

A constant voltage transformer is used in conjunction with variable voltage transformers to assure a constant power supply at each setting. The central heater and guard heater are controlled individually by the variable voltage transformers. The voltage and current to the central heater are monitored by means of a voltmeter and an ammeter, which are switched out of the circuit except when actually being read. The voltage to the guard heater is monitored constantly by a voltmeter.

All of the thermocouple readings are taken on a Leeds and Northrup K-3 potentiometer in conjunction with a galvanometer of 0.43 microvolts per mm deflection sensitivity.

To obtain mean sample temperatures above room temperature, water is circulated through the cooling section. For mean sample temperatures below room temperature, cold trichloroethylene is pumped through the cooling section. This coolant is chilled by circulating it through copper coils in a trichloroethylene dry-ice bath. Equilibrium conditions are certified before readings are taken.

Coefficients of thermal conductivity are calculated from the expression:

$$k_S = \frac{Q l_S}{A \Delta t} \qquad (1)$$

Q = total heat flow - Btu/hr
l_S = average thickness of specimen - inches
A = area of central heater section - square feet
ΔT = sum of temperature drops across each sample - °F

Theoretically, Q, the heat input, should split, with exactly half of the input flowing through each sample. The temperature drops indicate that this condition rarely exists. Instead, there is a slight unbalance in the heat flow. The above formula then permits a calculation of the arithmetic average for the two panels. In this calculation the temperatures are measured directly at the faces of the specimen by the "getters", resulting in a "direct" method.

As a check, the thermal conductivity is calculated for the specimen with a "series-resistance" or "composite" expression. This method utilizes the same run data, except that the temperature difference between the heater plate and the cold plate is utilized and, since the resistance of the filler is measured separately in the same apparatus, the following series-resistance equation can be used to determine the thermal conductivity of the specimen:

$$k_S = \frac{l_S}{(l_T/k_T) - (l_F/k_F)} \qquad (2)$$

l_S = thickness of the specimen - inches
k_S = thermal conductivity of the specimen - Btu in./hr ft^2°F
(l_T/k_T) = thermal resistance of the total composite of filler and specimen, calculated from the temperature difference between the hot and cold plate
(l_F/k_F) = thermal resistance of the filler alone, determined under the same conditions that exist for (l_T/k_T)

The (l_F/k_F) term for the gum rubber filler is determined both with and without copper plates inserted betwen the rubber pads to simulate interface resistance that is present during the evaluation of the specimens.

Improvement and Calibrations on the ASTM C177-45 Technique

The ASTM C177-45 guarded hot plate apparatus is only recommended for determining values below 5 Btu in./hr ft^2°F. Due to the higher conductivities of many of the new reinforced plastics such as the phenolic graphites and carbons, considerable work was necessary before the above procedures were incorporated, which provides accurate data between 5 and 10 Btu in./hr ft^2°F. The following is a resume' of the work and analysis performed which extended the range to 10 Btu in./hr ft^2°F.

It was decided at the beginning of the investigation that data from -50°F to 150°F would be determined using a filler of gum rubber and determining the conductivity of the specimen by both "direct" measurement of the temperature drop across the specimen and a "series-resistance" or "composite" method, as explained. From 150°F to the maximum temperature, the data would be obtained by using an asbestos filler and determining the conductivity by a "direct" calculation from the measured face temperatures of the specimen. Both methods were used at 150°F to determine if any uncertainty existed due to poor intimate contact resulting from either specimen or filler surface irregularities.

Considerable deviation of approximately 20% to 30% occurred between the values obtained for the "composite" method and the "direct" method for the higher conductivity materials. The evaluations with plexiglas and pyrex at that time indicated the following (see Table 1):

1. The "composite" method, when calibrated with pyrex and plexiglas, exhibited somewhat high values of 8 Btu in./hr ft^2°F at 150°F and 1.23 Btu in./hr ft^2°F at 150°F, respectively. The major difficulty was the great scatter between different data.

2. The "direct" method, when calibrated with pyrex, was in error by exhibiting values averaging about 20% low. However, the plexiglas calibration indicated excellent agreement.

The above results indicated that the conductivity data for values above 5 Btu in./hr ft^2°F should be determined using the composite method, with the direct method employed for the lower values. However, the composite method is much too critical under certain conditions, and data scatter was as high as 30%. By considering Equation 2 in close detail, it was found that normal experimental error in determining (l_F/k_F) can result in a magnified

error of k_s if (l_F/k_F) is critically close to (l_T/k_T). With certain conditions an error of 3% in (l_F/k_F) can result in a 10% to 50% error in k_s. Therefore, it was mandatory that the direct method be improved for use over the entire range of values, and that the composite be used only as a check.

It was determined that a majority of the error obtained with the direct method was due to the lack of intimate contact at the interfaces of the specimens when the load and fillers were improperly selected. This error was magnified (even percentage wise) when the conductivities were about 5 Btu in./hr $ft^2°F$. In order to obtain intimate contact at the interfaces, proper selection of compaction load and filler material for each test material are required. An extensive evaluation was performed of the effect on measured conductivity of increased compaction loading using either no filler material or fillers of gum rubber, Fiberfrax, or asbestos. The specimens used in this evaluation were plexiglas, pyrex, and other plastic materials, which represented a range of conditions including different surface finish, flatness, flexibility, and conductivity. Table 1 presents the calibration data obtained for pyrex and plexiglas in the 3" and 7" diameter and 14" square ASTM C177-45 guarded hot plate apparatuses.

Under the normal compaction load of approximately 600 pounds, the 3" diameter apparatus provided reliable data for plexiglas using either filler or no filler, and for pyrex using the filler only. Under the normal load the 14" apparatus provided accurate data for plexiglas; however, the values were occasionally low on the pyrex using the direct method of calculation. The 7" diameter apparatus provided data about 8% low for pyrex under normal load with a gum rubber filler. For plexiglas, the 7" diameter apparatus provided accurate data under normal compaction loads with no filler and gum rubber or Fiberfrax filler; however, the data were 7% low using an asbestos filler. Subsequent work indicated that the 7" apparatus was somewhat erratic, so the heater was rebuilt and the agreement with standards improved even more to within about 5%, although the trend remained similar. Such extensive data were not reobtained.

Under varying load, the 7" diameter apparatus with gum rubber filler provided values for pyrex that increased 7.5% as the load was increased from 100 pounds to 600 pounds and only increased 3% more from 600 pounds to 4000 pounds. The excessively high compaction pressures provided values on plexiglas with a gum rubber filler that were not orderly and were noticeably higher than reported in the literature for this material, regardless of the technique.

The data obtained with increasing load on the other plastic materials (not standards) demonstrated in most cases that an increase in compaction load from the normal 600 pounds did not increase the values significantly but did introduce unorderly changes. It was apparent, therefore, that excessively high loadings were neither required nor desirable. As a matter of fact, the bonds between the resin and reinforcement on some materials could be influenced, thermally, by such high pressures. Further, stress fields are created and data obtained here have indicated an influence of stress on the conductivity of the structures involved for a material such as plexiglas. The mechanism is probably one of the induced alignment of the chains.

The major requirement was to provide intimate thermal contact on all faces, which could be done by the proper selection of compaction load and filler, depending on the properties of the particular specimen. The actual load on the sandwich was more important than the pressure since it is the load and not the pressure that best correlates with flattening a curved plate or specimen. For example, it requires more load to flatten a 7" plate than it does a 14" plate. So, if the same pressure were maintained on the two apparatuses, the lower compaction force on the smaller one would not flatten the bow. The pressure would be important in providing deformations, locally, of the filler and/or specimen where a low or high spot may exist; however, the data on plexiglas and pyrex with rubber and Fiberfrax, particularly, clearly demonstrated that small compaction loads were sufficient to provide enough pressure to deform the filler into local areas. The compaction load needed was not as excessive as had been suggested in some literature in which the pressure was considered of major importance. An indication of the importance of the load-filler combination rather than pressure was apparent from the data, which provided higher conductivities on the 7" rig with the rubber filler and 600 pound load than on the same rig with no filler at 3000 pound load. Higher conductivities were obtained with the lower pressure by substituting the proper combination of load-filler.

From the above, it has been decided that the higher thermal conductivity materials can be evaluated accurately by the direct measurement method using a filler if the flat surfaces are held flat, and the compaction loads are held at a nominal level sufficient to provide intimate contact at the interfaces. The amount of loading depends on the flatness, the flexibility of the specimen, and the type of filler used. For very rigid materials like pyrex, it is doubtful if enough pressure could be applied when run without filler without breaking the specimen. No one technique is adequate for the determination of the conductivity of all specimens over the full temperature range. Careful judgement is required by the investigator in each case to select the compaction load, the filler (or no filler), the heat flow level and to evaluate the condition of the apparatus.

The above analysis led to the modifications and improvements which have been made on the ASTM apparatuses beyond those normally employed to assure better accuracy of the data. The screw loading device on the 14" apparatus has been modified to incorporate spring loading at the center and edge clamps to insure more uniform loading, and thus provide flatter surfaces and more intimate contact. The edges are monitored with 1 mil pull-out tabs to insure that no gaps existed in the plates. The thermocouple wires are more carefully placed along the isothermal surface of the specimen. The Fiberfrax paper has been adopted as a high temperature filler, since it conformed to any irregularities on the surface exceptionally well allowing the placement of the small thermocouple wires, electrically insulated with 0.003" teflon tape, without disrupting the intimate contact required. It has also been noted that increasing the heat level, and thus the temperature difference, across the specimen provides less deviation at the 150°F overlap temperature. The minimum heat flow level depends on the conductivity of the material and cannot be defined at a given temperature drop. The random deviation between values on the same specimen as evaluated with rubber filler from -50°F to 150°F, and with Fiberfrax filler from 150°F to 1000°F has been reduced to a maximum of about 5%. Past experience has shown that the Fiberfrax filler provides slightly higher data on 30% of the runs and slightly lower data on the remaining runs at the change-over temperature (from one filler to the other) at about 150°F.

Table 1 presents the many calibrations performed on the apparatuses for both before and after the above improvements were incorporated.

TABLE A1

CALIBRATIONS OF ASTM C177 APPARATUSES AND PROCEDURES WITH PLEXIGLAS AND PYREX 7740 STANDARDS AT ABOUT 150°F TO 200°F (DIRECT METHOD UNLESS OTHERWISE NOTED)

Apparatus	Plexiglas thermal conductivity Btu in./hr ft^2°F	Pyrex thermal conductivity Btu in./hr ft^2°F
14" rig with asbestos or rubber filler, composite method and 600 pounds	1.33 to 1.39	7.1 to 8.9
14" rig with asbestos filler and 600 pounds	1.17 to 1.20	5.96
14" rig and rubber filler and 600 pounds	1.19 to 1.22 to 1.30	7.35 to 7.39
14" rig with Fiberfrax filler and 600 pounds after improvements made	1.34	7.64 to 7.83
7" diameter rig with rubber filler and compaction of:		
100 pounds	1.25	-7.3%
600 pounds	1.26 to 1.09 with Q	0%, 7.74
1000 pounds	1.25	0%
3000 pounds	-	2.0%
4000 pounds	1.14 to 1.33 with Q	2.1%
7" diameter rig with asbestos filler and compaction of:		
100 pounds	-	
600 pounds	1.11 to 1.17	5.0
1000 pounds	1.11	
3000 pounds	-	
4000 pounds	1.16	
7" diameter rig with no filler and compaction load of:		
100 pounds	1.12	
600 pounds	1.21	4.0
1000 pounds	1.23	
3000 pounds	1.27	
4000 pounds	1.29	
7" diameter rig with Fiberfrax and 600 pounds after improvements made	1.14	7.13 to 8.1
3" diameter rig with rubber filler and 600 pounds	1.17	7.34 to 7.6
3" diameter rig with Fiberfrax filler and 600 pounds	1.15, 1.18, 1.19, 1.41 to 1.19	7.4 to 7.6
3" diameter rig with asbestos filler and 600 pounds	1.16, 1.16, 1.16	7.28
3" diameter rig without filler and 600 pounds	1.18 to 1.19	6.70 to 6.79

1. Literature and previous work reports the thermal conductivity of plexiglas to be 1.19.
2. Literature reports the thermal conductivity of 7740 pyrex to be from 7.1 to 8.1 at about 200°F by Knapp, American Ceramic Society, 1942, and the NBS, respectively. The NBS data are by the series resistance of composite technique. Prior values by the NBS using direct method were about 7.4 to 7.5.
3. Thicknesses of specimens vary with investigator.

Figure 1A. The 14-inch thermal conductivity apparatus

Figure 2A. The 7 and 3-inch thermal conductivity apparatus

APPENDIX B

HEAT CAPACITY TO 1000°F

The heat capacity to 1000°F is determined from data obtained in an adiabatic calorimeter. In this apparatus the heated specimen is dropped into a thermally guarded, calibrated cup, and the enthalpy is measured as a function of the increase in temperature of the cup. The heat capacity is the slope of the enthalpy versus temperature curve. A picture of the apparatus is shown in Figure 1.

A tubular furnace and a cold box are used to bring the specimens to temperature. By pivoting this equipment on a common post near the calorimeter, the samples are transferred to a position directly over the calorimeter cup. At this position the specimen is released from a suspension assembly that is triggered externally. Thermocouples located near the specimen are used to measure specimen temperature. The normal specimen size is about 1" x 1" x 1".

Elevated specimen temperatures are maintained by a manual setting of a variable voltage transformer, which controls the power input to the furnace. Cold sample temperatures are obtained by filling the cold box with dry ice and, when required, injecting liquid nitrogen vapors. The cold box consists of two concentric cylinders enclosed in a housing. The smaller cylinder (3" diameter by 16" high) is constructed of 1/4" mesh hardware cloth. The larger cylinder is made of galvanized sheet metal (15" diameter and 16" high). The annulus is partially filled with dry ice.

Specimens of the materials are heated or cooled to the desired temperature, and following a stabilization period, are dropped into the calorimeter cup. Adiabatic conditions are maintained during each run by manually adjusting the cup guard bath temperature.

The covered cup of the drop-type adiabatic calorimeter is approximately 2-1/2" in diameter by 2" deep. Three thermocouple wells are located in the bottom wall of the cup. The cup is mounted on cork supports, which rest in a silver-plated copper jacket. The jacket is immersed in a bath of ethylene glycol which is maintained at the temperature of the cup by means of a heater and copper cooling coils immersed in the liquid. Chilled trichloroethylene is circulated through the coils to cool the bath below ambient temperature when cold enthalpy measurements are made. A double-bladed stirrer maintains uniform bath temperature.

In the calorimeter six copper-constantan thermocouples, differentially connected between calorimeter cup and jacket, indicate temperature difference between cup and bath. The six thermocouples enable a difference of 0.03°F to be detected. This difference is maintained to within 0.15°F. During the runs, absolute temperature measurements of the cup are determined by means of the three thermocouple junctions, series connected, in the bottom of the calorimeter cup. All of the thermocouple readings are taken with instruments which permit readout to within 0.1°F; however, the system uncertainty is about 0.5°F.

The enthalpy of the specimen at any initial temperature is calculated from the following equation:

$$h = \frac{K}{W_S} (t_2 - t_1) \qquad (1)$$

where

h = enthalpy above t_2
K = calorimeter constant, 0.2654 Btu/°F
W_S = sample weight in lbs
t_1 = initial cup temperature in °F
t_2 = final cup temperature in °F

The calorimeter constant of 0.2654 Btu/°F was determined by measuring the enthalpy of an electrolytic copper specimen of known specific heat.

The enthalpy is referred to a common base temperature of 85°F using the following linear interpolation:

$$h_{85} = h \frac{(t_3 - 85)}{(t_3 - t_2)} \qquad (2)$$

where

h_{85} = enthalpy above the reference temperature of 85°F in Btu/lb
t_3 = initial sample temperature in °F

The base of 85°F is used because this is usually near the actual final cup temperature.

The enthalpy-temperature curve established is used to determine heat capacity (specific heat) by measuring its slope at different temperatures. This is done both graphically and by analytical methods which first fit the enthalpy data to an equation of the following type:

$$h_{85} = aT + bT^2 + cT^{-1} + d \qquad (3)$$

The temperature (T) employed usually is in degrees Rankine. While this equation may not provide the best definition of the enthalpy data over the entire temperature range, it does anticipate the theoretical behavior and is consistent with methods recommended in WADC TR57-308 and by K. K. Kelley.[1] The derivative of this equation, the heat capacity, is used with the constant "c" adjusted so that the analytical solution agrees with the value determined graphically at 150°F. This technique is similar to that of Kelley in forcing the heat capacity equation through a known value. The equations are developed using a digital computer.

The accuracy of the apparatus has been confirmed by measuring the enthalpy of sapphire and other standard specimens and comparing the results to literature values. The results of the comparison on sapphire are shown in Table 1. From these and other data the overall uncertainty of the apparatus was established at ±3 percent.

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[1] Kelley, K. K., "Contributions to Data on Theoretical Metallurgy," Vol. XIII High Temperature Heat Content, Heat Capacity, and Enthalpy Data for Elements and Inorganic Compounds, Bulletin 584, U. S. Bureau of Mines, November, 1958.

TABLE B1

COMPARISON OF THE SPECIFIC HEAT OF SAPPHIRE OBTAINED BY THE ADIABATIC CALORIMETER TO SEVERAL OTHER SOURCES

SRI adiabatic calorimeter		SRI ice calorimeter		Armour Research Foundation		Linde Company		International critical tables	
Temp °F	Specific heat Btu/lb°F	Temp °F	Specific heat Btu/lb°F	Approx. temp. °F	Specific heat Btu/lb°F	Approx. temp. °F	Specific heat Btu/lb°F	Temp. °F	Specific heat Btu/lb°F
490	0.233	497	0.210	500	0.263	500	0.2125		
996	0.240	1008	0.241	1000	0.280	1000	0.2265	922	0.239

Figure B1. Heat capacity apparatus

APPENDIX C

THERMAL EXPANSION TO 1800°F

Thermal expansion measurements are made utilizing quartz tube dilatometers of the Bureau of Standards design. The dial gages (B. C. Ames Co., Model 212, Shockless) are graduated in 0.0001-inch divisions with a total range of 0.500 inch. The manufacturer's stated mechanical accuracy for any given reading is ±0.0001 inch at any point in the range. This accuracy has been checked with a precision micrometer.

The extensions from the dial, which are made of stainless steel, are finned to facilitate cooling. The temperatures of the fins are continually monitored and air cooled when necessary to eliminate differential expansion between the dial gage mount and the extension; see Figure 1.

For temperatures above room temperature, each dilatometer is heated by an individual heater. The temperature of the heater is maintained by a manual setting of a variable voltage transformer.

Cold specimen temperatures are obtained by use of a Dewar flask filled with dry ice and trichloroethylene. The flask surrounds the dilatometer tubes and the cold liquid level rises to a height above the specimens.

Liquid nitrogen is used in the Dewar flask for temperatures down to -300°F. A cooling coil has also been designed to provide better control of temperatures in the cryogenic range.

Thermocouples are placed at each end and the center of the specimens to monitor the temperature throughout. The specimens are nominally 1/2-inch diameter by 3 inches in length with the ends rounded on a 3-inch radius. Other diameters and cross-sectional configurations are employed where necessary due to configuration of supplied material.

To calibrate the dilatometers we employ a fused silica specimen, the expansion of which is known and is shown in Figure 2.

The accuracy of the apparatus to 1800°F has been checked by running the NBS copper standard and other in-house standards of graphite and nickel. Figures 3, 4 and 5 include the expansion values measured in the quartz dilatometers on these standards. Note the excellent agreement between the measured values and the data reported by NBS on the copper. For the graphite and nickel standards, good agreement was observed between the values measured in the quartz dilatometer and that reported in the literature and the values measured at SRI by optically tracking.

The above data and our experience have demonstrated the excellent precision and accuracy of this equipment. We have observed no systematic uncertainty with the equipment and, based on 5 runs with the graphite standard, the random uncertainty is $\pm 0.05 \times 10^{-3}$ in./in. at 1500°F with a 95 percent confidence interval.

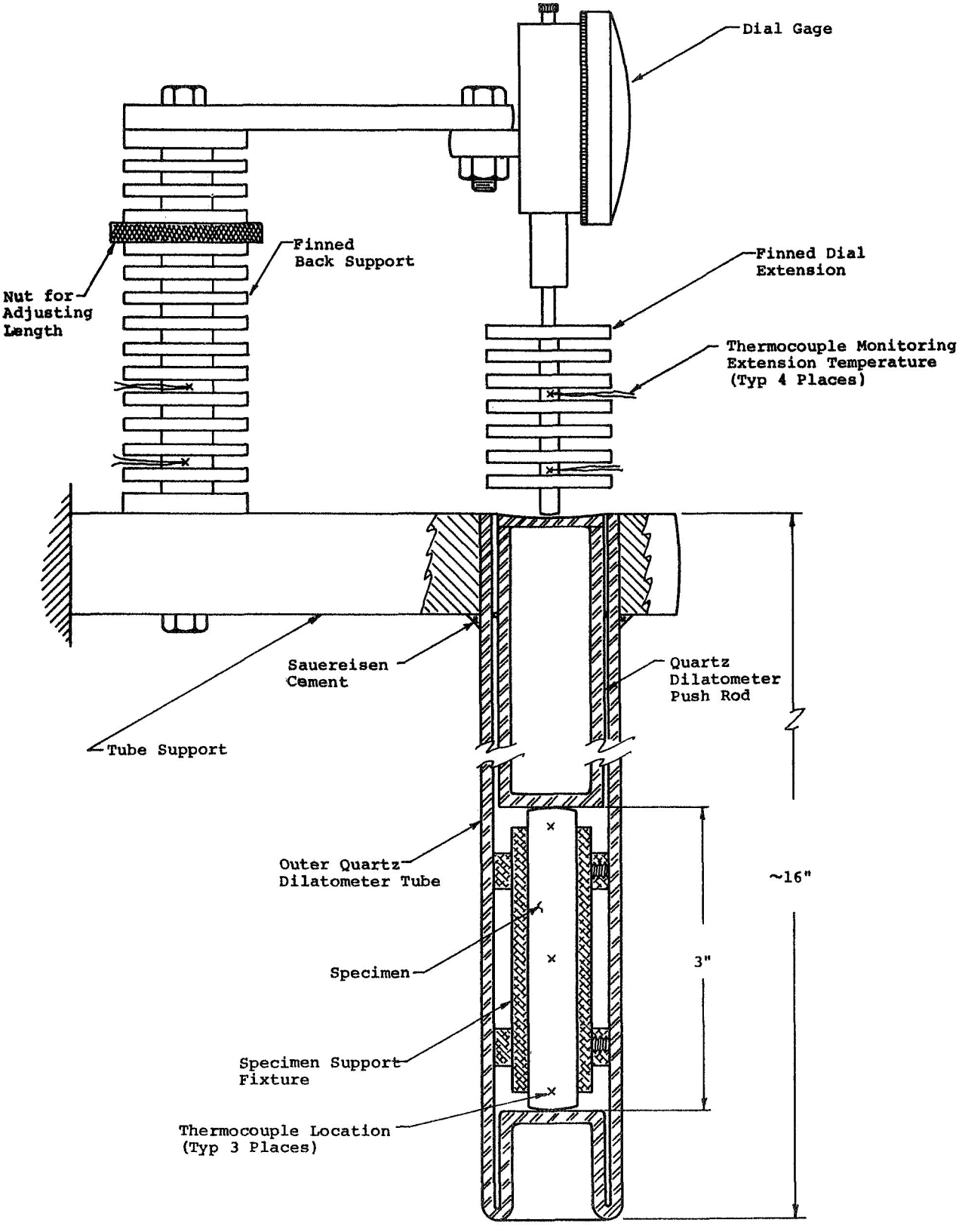

Figure C1. Assembly of quartz tube dilatometer for thermal expansion measurements

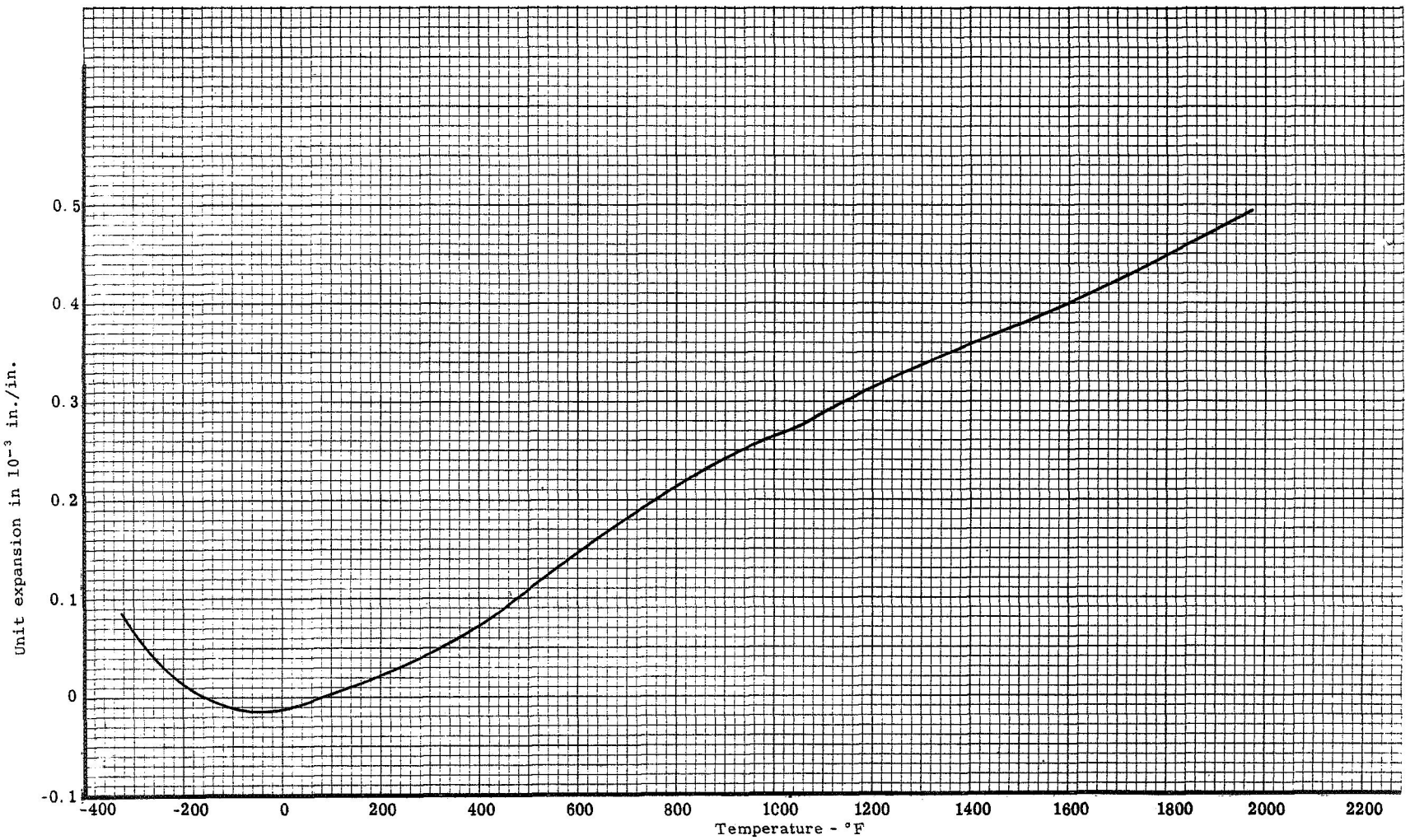

Figure C2. Thermal expansion of fused silica (taken from Souder and Hidnert, "Measurements on Thermal Expansion of Fused Silica", Scientific Papers of the Bureau of Standards, No. 524)

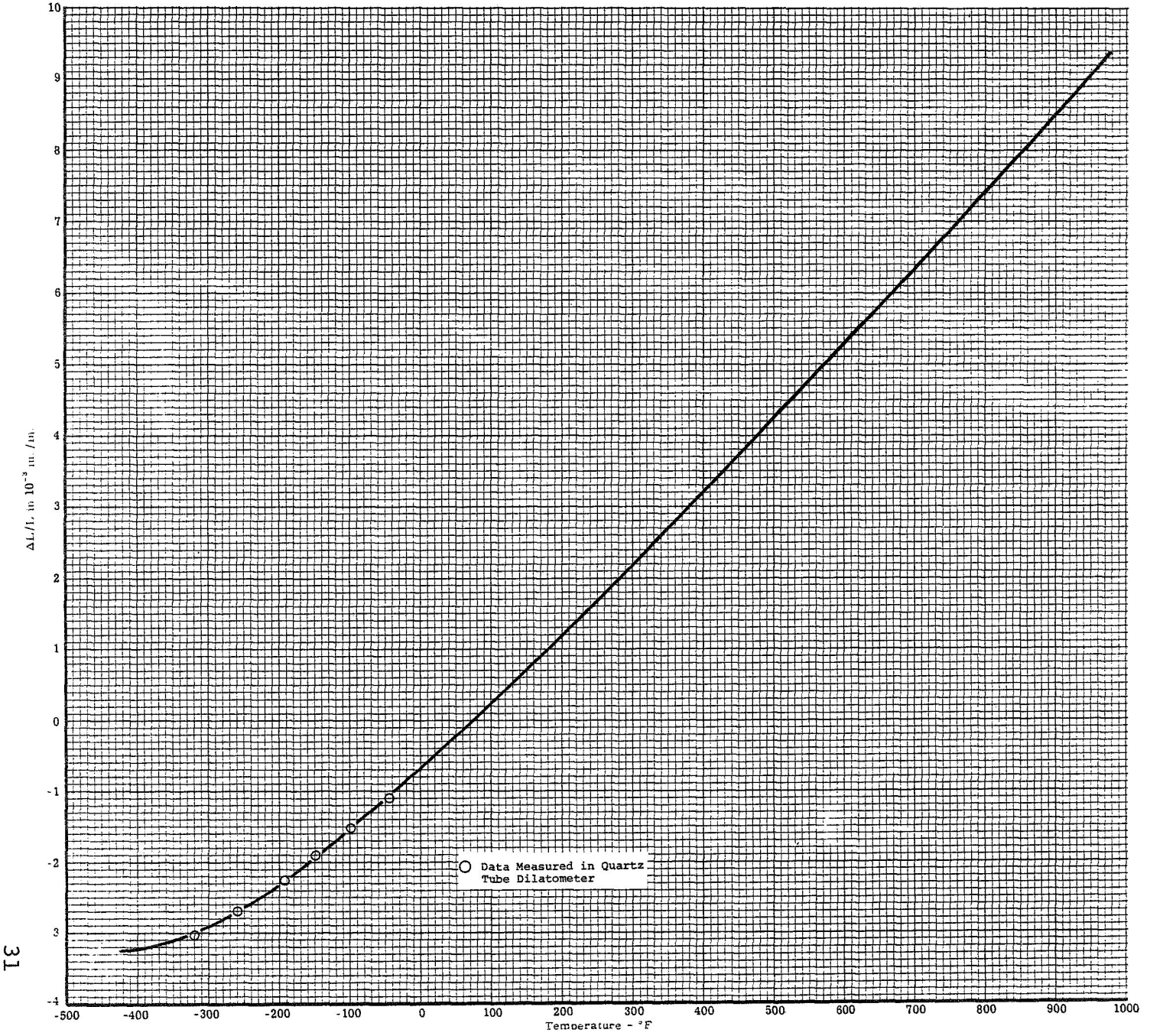

Figure C3. Thermal expansion of NBS Copper Standard SRM 736

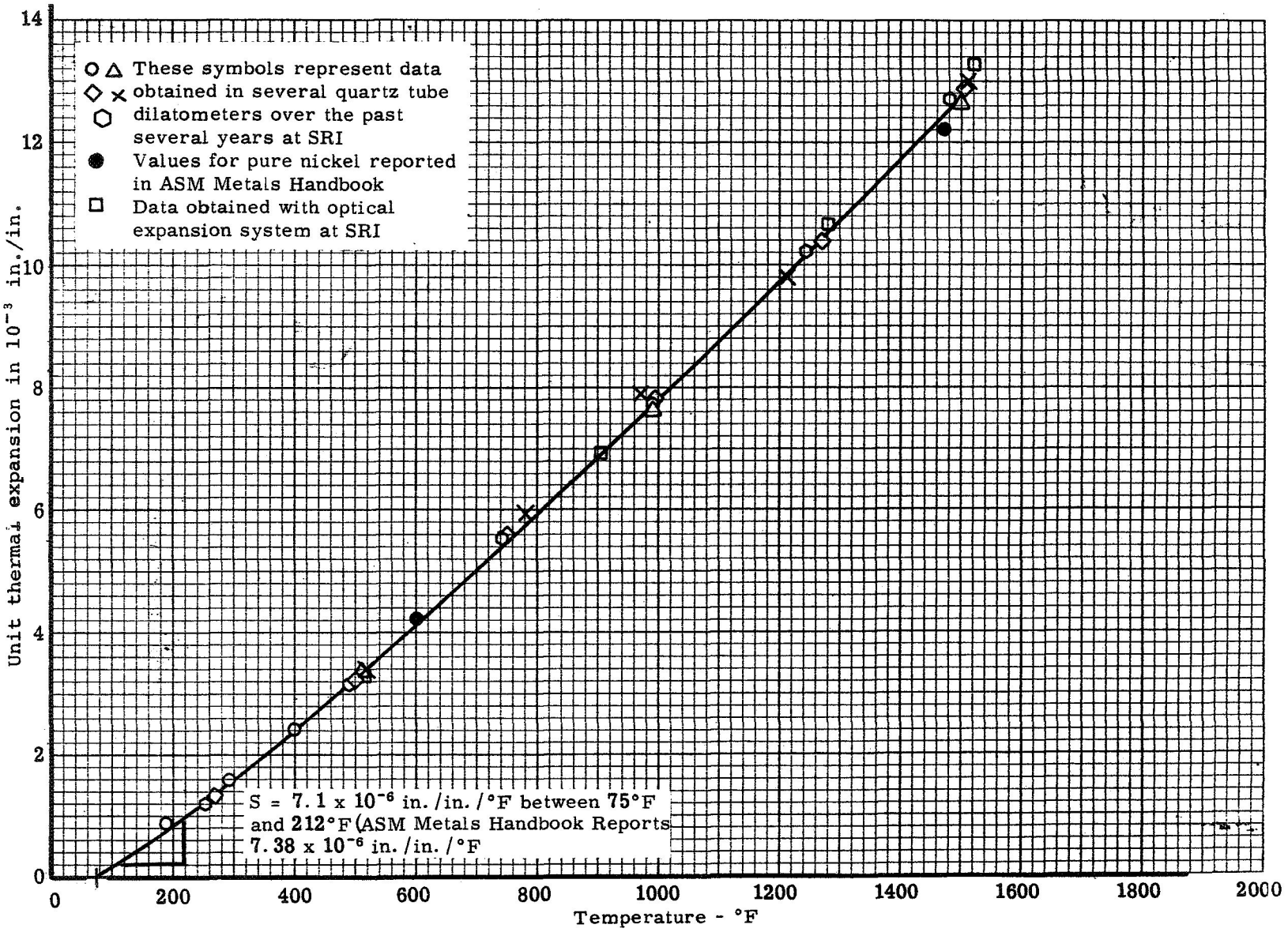

Figure C4. Expansion of "A" Nickel (Calibration Standard Specimen)

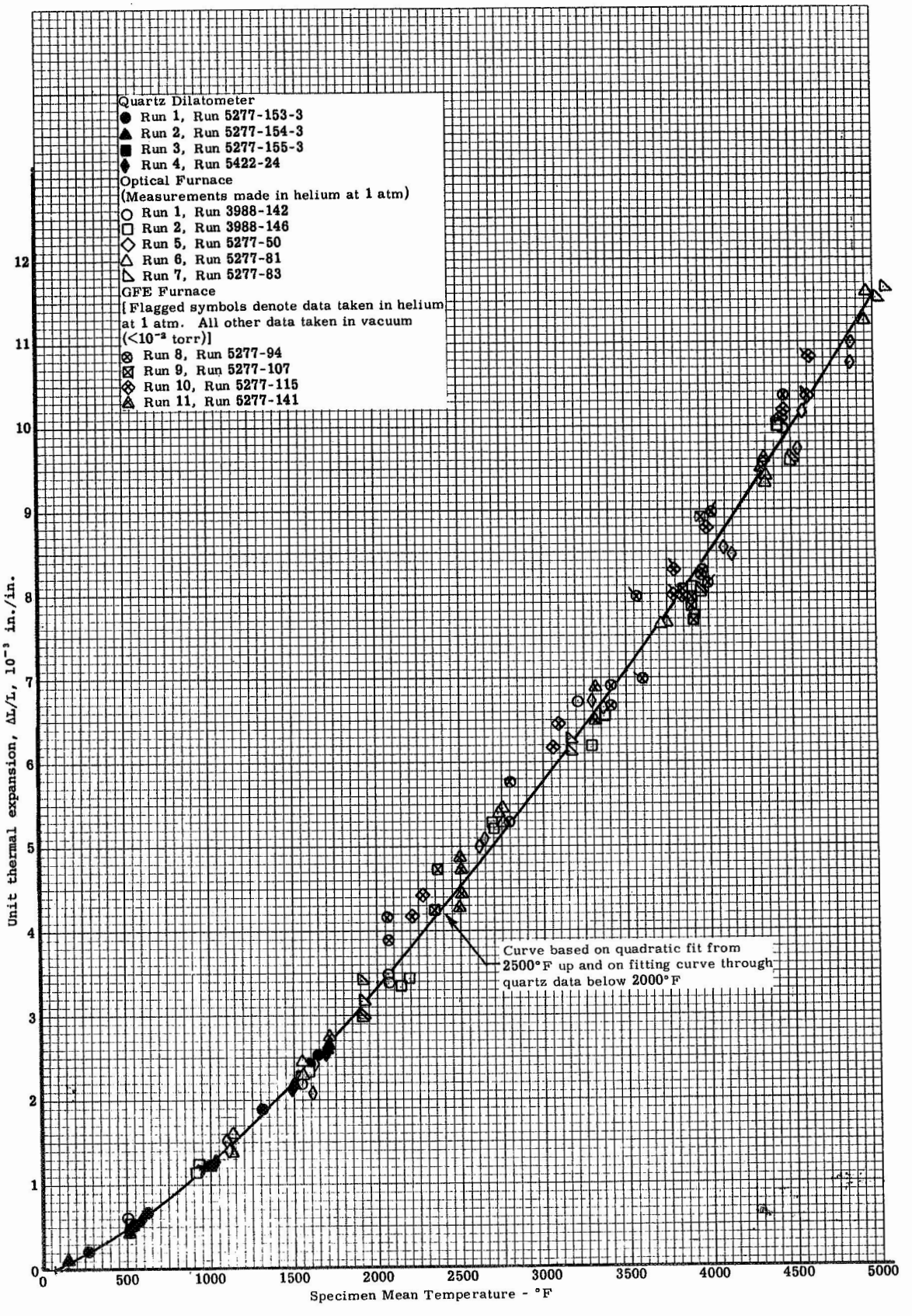

Figure C5. Thermal expansion of ATJ graphite (wg) Standard No. 5 by in-house calibration

TABLE 1

COMPOSITIONS OF ABLATIVE MATERIALS EVALUATED UNDER SUBTASK A

Material designation	Composition (percent by weight)	Manufacturer
MG-36	25 - Silicone Resin, Dow Corning Sylgard 182 71 - Phenolic Microballoons, Union Carbide BJO-0930 4 - Quartz Fibers, Johns-Manville Microquartz	
E6A7	50 - RTV-602, General Electric 20 - Powdered Phenolic, Union Carbide BRP-5549 25 - Phenolic Spheres, Union Carbide BJO-0930 5 - Dimethyl Oil, General Electric SF-69	
S-20T	Foamed Silicone Elastomer Carbon Black Filler Phenolic-Glass Honeycomb Glassy Fibers } Composition Proprietary	McDonald-Douglas Astronautics Company-East
SLA-561	Silicone Elastomer Cork Fibers Microspheres } Composition Proprietary	Martin-Marietta Corp. Denver Division

TABLE 2

BULK DENSITY OF MG-36, SILICONE-PHENOLIC

Specimen	Bulk density (gm/cm^3)
(ASTM C177 Guarded Hot Plate Apparatus)	
Specimen 1 Top Disc	0.252
Bottom Disc	0.251
Specimen 2 Top Disc	0.251
Bottom Disc	0.252
Specimen 5 (Thermal Expansion)	0.258
Specimen 6 (Thermal Expansion)	0.255

Table 3

BULK DENSITY OF E6A7, SILICONE-PHENOLIC

Specimen	Bulk density (gm/cm^3)
Specimen 1, Top Disc, Billet 6A	0.653
Specimen 1, Bottom Disc, Billet 6A	0.652
Specimen 2, Top Disc, Billet 8A	0.652
Specimen 2, Bottom Disc, Billet 8A	0.651

TABLE 4

BULK DENSITY OF SLA-561, FILLED CORK

Specimen	Bulk density (gm/cm^3)
(ASTM C177 Guarded Hot Plate Apparatus)	
Specimen 1 Top Disc	0.224
Bottom Disc	0.222
Specimen 2 Top Disc	0.233
Bottom Disc	0.227
Specimen 5 (Thermal Expansion)	0.232
Specimen 6 (Thermal Expansion)	0.227

TABLE 5

BULK DENSITY OF VIRGIN S-20T, BLOWN SILICONE ELASTOMER WITH CARBON BLACK FILLER IN PHENOLIC-GLASS HONEYCOMB

Specimen		Bulk density (gm/cm^3)
(Specimens for ASTM C177 Guarded Hot Plate Apparatus - see Cutting Plan for Locations)		
Specimen 1	Disc 1	0.329
	Disc 2	0.345
Specimen 2	Disc 3	0.340
	Disc 4	0.356

TABLE 6

THERMAL CONDUCTIVITY OF MG-36, SILICONE-PHENOLIC
(ASTM C177 GUARDED HOT PLATE APPARATUS)

Average specimen mean temperature-K	Total heat input watts	Average specimen ΔT K	Specimen thickness[1] K	Specimen thermal conductivity 10^{-2} W/m-K	Time to temperature hr
Specimen 1, Billet MG-36 Gum Rubber Filler Bulk Density: Top Disc - 0.252 gm/cm³ Bottom Disc - 0.251 gm/cm³ Gum Rubber Filler					
152.8	2.75	228.0	0.6339	3.76	4.0
148.1	2.79	230.5	0.6339	3.78	5.2
191.5	5.69	356.3	0.6339	4.97	6.7
191.4	5.55	355.4	0.6339	4.87	7.2
253.5	2.57	138.2	0.6339	5.81	3.5
254.1	2.57	139.1	0.6339	5.76	4.0
344.7	2.65	128.0	0.6339	6.46	3.0
345.5	2.74	130.0	0.6339	6.57	3.2
Fiberfrax and Gum Rubber Filler					
360.6	2.71	134.6	0.6296	6.24	3.2
360.8	2.69	134.9	0.6296	6.17	3.5
399.8	4.64	216.3	0.5946	6.28	4.5
400.2	4.62	217.0	0.5946	6.23	5.0
Fiberfrax, Asbestos Pads and Gum Rubber Filler					
445.8	3.89	149.2	0.5138	6.59	7.0
447.2	3.81	149.0	0.5138	6.47	8.0
450.8	3.64	152.2	0.5102	6.00	8.0
451.6	3.65	152.3	0.5102	6.02	8.5
496.9	4.56	173.8	0.4528	5.84	4.5
497.1	4.56	172.4	0.4528	5.87	5.0

TABLE 6 (CONCLUDED)

Average specimen mean temperature-K	Total heat input watts	Average specimen ΔT K	Specimen thickness[1] m	Specimen thermal conductivity 10^{-2} W/m-K	Time to temperature[2] hr
Specimen 2, Billet MG-36 Gum Rubber Filler Bulk Density: Top Disc - 0.251 gm/cm^3 Bottom Disc - 0.252 gm/cm^3 Gum Rubber Filler					
154.6	2.61	220.9	0.6339	3.69	6.5
208.6	5.53	374.2	0.6339	4.60	4.5
262.8	2.63	150.3	0.6339	5.46	4.5
262.7	2.63	149.6	0.6339	5.49	5.0
347.5	2.62	138.2	0.6339	5.91	5.0
347.7	2.62	138.9	0.6339	5.88	5.5
Fiberfrax and Gum Rubber Filler					
366.8	2.63	146.0	0.6367	5.63	6.0
364.6	2.62	142.2	0.6347	5.75	2.5
Fiberfrax, Asbestos Pads and Gum Rubber Filler					
406.5	4.56	230.5	0.6055	5.89	4.5
406.3	4.56	230.5	0.6055	5.89	4.0
463.7	3.83	159.3	0.4892	5.78	3.0
464.3	3.83	159.4	0.4892	5.78	3.5
502.8	4.55	177.6	0.4292	5.40	5.3
502.7	4.55	175.3	0.4292	5.40	5.0

[1]Thermal conductivity values based on measured thickness at each temperature level.

[2]Time to temperature implies the time elapsed between adjustment of power and obtaining data.

[3]Area of central heater = 18.29 cm^2

TABLE 7

THERMAL CONDUCTIVITY OF SLA-561, FILLED CORK
(ASTM C177 GUARDED HOT PLATE APPARATUS)

Average specimen mean temperature - K	Total heat input watts	Average specimen ΔT K	Specimen thickness[2] cm	Specimen thermal conductivity W/m-K	Time to temperature[3] hr
Specimen 1					
Bulk Density: Disk No. 3, Top: 0.224 gm/cm^3					
Disk No. 4, Bottom: 0.222 gm/cm^3					
Gum Rubber Filler					
175	2.54	162	0.953	4.1×10^{-2}	5.41
175	2.54	161	0.953	4.1×10^{-2}	
Specimen thickness reduced					
290	3.70	115	0.636	5.6×10^{-2}	4.83
290	3.68	115	0.636	5.6×10^{-2}	6.58
Fiberfrax and Gum Rubber Filler					
286	2.36	74	0.621	5.4×10^{-2}	2.75
286	2.36	74	0.621	5.4×10^{-2}	3.50
374	2.63	76	0.608	5.8×10^{-2}	6.25
376	2.62	78	0.608	5.6×10^{-2}	7.50
417	3.93	114	0.598	5.6×10^{-2}	7.58
419	3.93	115	0.598	5.6×10^{-2}	8.33
Fiberfrax - Asbestos Filler					
452	3.07	81	0.592	6.1×10^{-2}	1.17
453	3.06	82	0.592	6.0×10^{-2}	1.92
508	3.96	98	0.525	5.8×10^{-2}	4.58

Notes:
1. Diameter of central heater = 4.826 cm (Area = 18.29 cm^2).
2. Thermal conductivity values based on measured thickness at each temperature level.
3. Time to temperature implies the time elapsed between adjustment of power and obtaining data.
4. Data obtained under a constant compaction pressure of 1.65×10^5 N/m^2.

TABLE 8

THERMAL CONDUCTIVITY OF SLA-561, FILLED CORK
(ASTM C177 GUARDED HOT PLATE APPARATUS)

Average specimen mean temperature - K	Total heat inputs watts	Average specimen ΔT K	Specimen thickness[2] cm	Specimen thermal conductivity W/m - K	Time to temperature[3] hr
Specimen 2 Bulk density: Disk No. 1, Top: 0.233 gm/cm^3 Disk No. 2, Bottom: 0.227 gm/cm^3					
Gum Rubber Filler					
266	2.57	79	0.638	5.7×10^{-2}	2.75
265	2.57	82	0.638	5.5×10^{-2}	3.75
265	2.56	82	0.638	5.4×10^{-2}	4.50
153	2.60	115	0.638	3.9×10^{-2}	1.25
155	2.60	117	0.638	3.9×10^{-2}	2.25
183	3.82	150	0.638	4.4×10^{-2}	----
Fiberfrax and Gum Rubber Filler					
288	2.53	71	0.629	6.1×10^{-2}	3.50
289	2.53	72	0.629	6.0×10^{-2}	4.50
354	1.96	55	0.617	6.0×10^{-2}	5.00
373	2.59	72	0.617	6.1×10^{-2}	7.00
413	4.08	109	0.611	6.3×10^{-2}	3.75
413	4.12	109	0.611	6.3×10^{-2}	5.00
Fiberfrax and Asbestos Filler					
470	3.47	89	0.588	6.3×10^{-2}	8.08
470	3.47	88	0.588	6.3×10^{-2}	9.00

Notes:
1. Diameter of central heater = 4.826 cm (Area = 18.29 cm^2).
2. Thermal conductivity values based on measured thickness at each temperature level.
3. Time to temperature implies the time elapsed between adjustment of power and obtaining data.
4. Data obtained under a constant compaction pressure of 1.65×10^5 N/m^2.

TABLE 9

THERMAL CONDUCTIVITY OF BILLETS 6A AND 8A OF E6A7, SILICONE-PHENOLIC, ASTM C177 GUARDED HOT PLATE APPARATUS

Av specimen mean temp. K	Total heat input watts	Av specimen ΔT K	Specimen thickness[1] cm	Specimen thermal conductivity W/m-K	Time to temp[2] hr
Specimen 1, Billet 6A Gum rubber filler material Bulk density: Top Disc - 0.653 gm/cm^3 Bottom Disc - 0.652 gm/cm^3					
349.2	2.66	65.50	0.9545	0.106	4.0
349.0	2.62	65.32	0.9545	0.105	5.0
Specimen 2, Billet 8A Gum rubber filler material Bulk density: Top Disc - 0.652 gm/cm^3 Bottom Disc - 0.651 gm/cm^3					
342.3	2.72	67.38	0.9535	0.105	3.0
342.5	2.71	67.29	0.9535	0.105	3.5

1. Thermal conductivity values based on measured thickness at each temperature level.
2. Time to temperature implies the time elapsed between adjustment of power and obtaining data.
3. Area of central heater = 18.29 cm^2

TABLE 10

THERMAL CONDUCTIVITY OF VIRGIN S-20T, BLOWN SILICONE ELASTOMER WITH CARBON BLACK FILLER IN PHENOLIC-GLASS HONEYCOMB (ASTM C177 GUARDED HOT PLATE APPARATUS)

Average specimen mean temperature K	Total heat input watts	Average specimen ΔT K	Specimen thickness[2] cm	Specimen thermal conductivity W/m-K	Time to temperature[3] hr
Specimen 1					
Bulk density: Disc 1, top 0.329 gm/cm^3; initial weight: 11.299 g; final weight: 11.275 g					
Disc 2, bottom 0.345 gm/cm^3; initial weight: 11.944 g; final weight: 11.921 g					
Gum rubber filler					
356	3.35	75.0	0.638	0.078	6.0
344	2.77	60.6	0.638	0.080	51.0
344	2.77	61.6	0.638	0.079	51.3
Specimen 2					
Bulk density: Disc 3, top 0.340 gm/cm^3; initial weight: 11.499 g; final weight: 11.486 g					
Disc 4, bottom 0.356 gm/cm^3; initial weight: 12.240 g; final weight: 12.227 g					
Gum rubber filler					
338	2.32	52.7	0.635	0.076	6.2
338	2.32	52.6	0.635	0.077	6.7

Notes:
1. Diameter of central heater = 4.826 cm (area = 18.29 cm^2).
2. Thermal conductivity values based on measured thickness at each temperature level.
3. Time to temperature implies the time elapsed between adjustment of power and obtaining data.
4. Data obtained at compaction pressure of 1.65 x 10^5 N/m^2.

TABLE 11

ENTHALPY OF MG-36, SILICONE-PHENOLIC

Specimen	Run	Initial cup temp. K	Final cup temp. K	Change in cup temp. K	Initial sample temp. K	Initial wt. of sample g	Final wt of sample g	Enthalpy $h=\frac{K}{W_s}(t_2-t_1)$ 10^3 Joules/kg	Enthalpy 10^3 Joules/kg	
									Above 303K	Above 273K
1	1	298.88	298.02	-0.86	207	3.3049	3.3039	-131	-138	-98
	2	295.33	294.81	-0.52	231	3.3039	3.3240	-79	-89	-49
	3	297.01	297.67	0.66	346	3.3240	3.2530	102	91	131
2	1	296.47	295.74	-0.72	212	3.5945	3.6104	-100	-109	-69
	2	295.93	295.23	-0.70	213	3.6104	3.6051	-98	-107	-67
	3	294.82	294.46	-0.36	251	3.6051	3.5870	-51	-61	-21
3	1	297.05	296.50	-0.55	178	1.9420	1.8746	-148	-156	-116
	2	298.38	298.67	-0.30	341	1.8746	1.8374	82	74	114
4	1	296.83	296.31	-0.52	255	3.8970	3.8987	-67	-78	-38
	2	297.30	299.31	-2.01	500	3.8987	3.1342	323	314	354
5	1	298.28	297.45	-0.83	404	2.7758	2.6007	161	152	192
	2	296.41	295.40	1.01	447	2.6007	2.3507	217	206	246
6	1	297.05	296.39	-0.66	400	2.2143	2.0705	161	151	191
	2	295.72	296.75	1.03	449	2.0705	2.0266	256	246	286
	3	295.22	296.52	1.30	499	2.0266	1.9863	330	319	359
7	1	297.66	298.20	0.54	340	4.6770	4.4595	61	55	95
	2	296.49	300.33	3.84	460	4.4595	4.1090	471*	463	503
8	1	298.15	300.80	2.65	448	4.6770	4.1668	320	316	356
9	1	297.95	302.34	4.39	470	4.4895	4.1845	528*	526	566
10	1	295.37	297.02	1.65	445	4.1500	3.9782	209	200	240
	2	295.14	297.61	2.47	533	3.9782	3.2195	386	378	418
11	1	297.02	299.08	2.06	447	3.8962	3.7485	277	270	309

[1]K (Calorimeter constant) = 503.9 Joules/ K

*Specimen smoked

TABLE 12

ENTHALPY OF SLA-561, FILLED CORK

Specimen	Run	Initial cup temp. K	Final cup temp. K	Change in cup temp. K	Initial sample temp. K	Initial wt of sample g	Final wt of sample K	Enthalpy $h=\frac{K}{W_s}(t_2-t_1)$ 10^3 Joules/kg	Enthalpy 10^3 Joules/kg Above 303K	Above 273K
1	1	297.25	296.54	-0.70	215.0	3.8114	3.7998	-92.8	-100.2	-68.2
	2	298.09	297.37	-0.73	208.9	3.7997	3.7574	-97.9	-104.1	-72.1
	3	296.94	296.33	-0.62	210.6	3.7574	3.7584	-83.1	-89.6	-57.6
	4	296.92	296.45	-0.47	240.0	3.7584	3.7544	-63.1	-70.4	-38.4
2	1	297.87	296.87	-1.00	148.3	3.4638	3.4639	-145.5	-151.5	-119.5
	2	296.28	296.72	0.44	336.1	3.4639	3.4506	64.3	56.4	88.4
	3	297.37	298.38	1.01	396.7	3.4506	3.4270	148.5	141.5	173.5
3	1	296.54	296.01	-0.53	215.0	3.1319	3.1315	-85.3	-92.6	-60.6
	2	291.17	296.65	-0.52	208.9	3.1313	3.1049	-83.7	-89.7	-57.7
	3	296.87	296.06	-0.81	148.3	3.1015	3.0915	-132.0	-138.2	-106.2
	4	296.74	297.19	0.45	340.0	3.0915	3.0743	73.8	63.7	95.7
	5	299.47	300.31	0.82	395.6	3.0518	3.0500	135.5	131.6	163.6
4	1	298.28	300.48	2.20	445.0	5.9943	5.8565	189.3	186.0	218.0
5	1	298.37	300.56	2.19	447.4	5.3312	5.1800	213.0	209.5	241.5
	2	298.92	301.85	2.93	500.1	5.1800	5.0953	289.8	288.1	320.1
6	1	297.82	299.98	2.16	418.5	5.5170	5.3898	201.9	196.8	228.8
	2	296.78	300.02	3.24	497.9	5.3898	5.2388	306.4	301.8	333.8
7	1	297.61	299.45	1.84	415.6	5.4880	5.3772	172.4	167.1	199.1
	2	297.83	301.14	3.31	501.4	5.3772	5.1455	324.1	321.1	353.1

1. K (Calorimeter Constant) = 503.9 Joules/ K

TABLE 13

ENTHALPY OF BILLETS 6A AND 8A OF E6A7, SILICONE-PHENOLIC

Specimen	Run	Initial cup temp. K	Final cup temp. K	Change in cup temp. K	Initial sample temp. K	Initial wt of sample g	Final wt of sample g	Enthalpy[1] $h = \frac{K}{W_s}(t_2-t_1)$ 10^3 Joules/kg	Enthalpy 10^3 Joules/kg	
									Above 303K	Above 273K
Spec 1, Billet 6A	1	297.85	296.49	-1.36	244	7.0655	7.0652	-97	-106	-68
	2	295.42	297.82	2.40	403	7.0652	6.9925	173	164	202
	3	297.61	301.59	3.98	485	6.9925	6.8436	293	291	329
Spec 2 Billet 8A	1	296.45	295.04	-1.41	227	7.5146	7.5185	-94	-105	-67
	2	297.61	299.97	2.36	405	7.5185	7.4335	160	155	193
Spec 3 Billet 8A	1	301.43	304.54	3.11	471	6.4567	6.2955	249	251	289

1. K (calorimeter constant) = 503.9 Joules/K

TABLE 14

ENTHALPY OF VIRGIN S-20T, BLOWN SILICONE ELASTOMER
WITH CARBON BLACK FILLER IN PHENOLIC-GLASS HONEYCOMB
(ADIABATIC CALORIMETER)

Spec	Run	Initial cup temp. K	Final cup temp. K	Change in cup temp. K	Initial sample temperature K			Initial wt of sample g	W_s, final wt of sample g	Enthalpy $h=\frac{K}{W_s}(t_2-t_1)$ Joules/kg	Enthalpy Joules/kg	
					Inside specimen	Surface of specimen	Average				Above 303K	Above 273K
1	2	297.61	298.36	0.75	-	374	374	3.6210	3.6065	10.5×10^4	9.9×10^4	13.9×10^4
	3	300.50	301.77	1.27	-	429	429	3.6065	3.5980	17.8×10^4	17.6×10^4	21.6×10^4
	4	301.92	301.18	-0.74	226	226	226	3.5980	3.6102	-10.3×10^4	-10.5×10^4	-6.5×10^4
2	2	298.34	299.22	0.88	-	374	374	4.1354	4.1205	10.8×10^4	10.3×10^4	14.3×10^4
	3	299.06	300.55	1.49	-	429	429	4.1205	4.1117	18.3×10^4	18.0×10^4	22.0×10^4
	4	302.77	301.97	-0.80	226	225	226	4.1117	4.1261	-9.8×10^4	-9.9×10^4	-5.9×10^4

1. K (Calorimeter Constant) = 503.7 Joules/ K

TABLE 15

THERMAL EXPANSION OF MG-36 SILICONE-PHENOLIC
MEASURED IN QUARTZ DILATOMETER

Specimen No.	Time	Temperature No. 1 K	Temperature No. 2 K	Temperature No. 3 K	Average temperature K	Observed total elongation 10^{-3} cm	Observed unit elongation 10^{-3} cm/cm	Unit elongation correction for dilatometer motion 10^{-3} cm/cm	Corrected specimen unit elongation 10^{-3} cm/cm
Specimen 5			Initial length: 7.5798 cm			Initial weight: 2.4551 g			
Run 1			Final length: 7.4510 cm			Final weight: - g			
Density 0.258 gm/cm^3									
Log 5184-100									
		298.3	298.3	298.3	298.3	0.00	0.00	0.00	0.00
		153.8	153.8	153.8	153.8	-49.68	-6.55	0.01	-6.54
		180.0	180.0	180.0	180.0	-42.49	-5.61	0.00	-5.61
		248.3	248.3	248.3	248.3	-20.88	-2.75	-0.01	-2.76
		298.8	298.8	298.8	298.8	-1.14	-0.15	0.00	-0.15
		349.4	349.4	349.4	349.4	11.86	1.56	0.02	1.58
		406.0	406.0	406.0	406.0	-62.05	-8.19	0.04	-8.15
		452.0	452.0	452.0	452.0	-82.22	-10.85	0.06	-10.79
		298.3	298.3	298.3	298.3	-86.91	-11.36	0.00	-11.36
Specimen 6			Initial length: 7.6085 cm			Initial weight: 2.4199 g			
Run 1			Final length: 7.6057 cm			Final weight: - g			
Density 0.255 gm/cm^3									
Log 5184-101	5:35	298.7	298.7	298.7	298.7	0.00	0.00	0.00	0.00
	6:19	255.7	255.9	259.8	256.8	-12.50	-1.64	-0.01	-1.65
	6:57	225.1	225.4	228.7	226.4	-19.51	-2.56	-0.02	-2.58
	7:57	181.5	183.7	184.3	183.2	-36.60	-4.81	-0.01	-4.82
	8:09	167.6	168.7	162.6	166.3	-42.37	-5.57	0.00	-5.57
	8:20	142.6	142.6	146.5	143.9	-51.89	-6.82	0.01	-6.81
	8:59	172.3	174.3	160.4	169.0	-45.67	-6.00	0.00	-6.00
	9:28	198.2	198.4	196.5	197.7	-32.03	-4.21	-0.01	-4.22
	9:54	229.5	231.2	224.8	228.5	-19.05	-2.50	-0.02	-2.52
	10:20	254.8	255.0	252.0	254.1	-10.57	-1.39	-0.01	-1.40
	10:35	255.7	255.9	254.8	255.5	-9.78	-1.29	-0.01	-1.30
	9:00	295.1	295.1	295.1	295.1	-3.25	-0.43	0.00	-0.43

TABLE 15 CONCLUDED

Specimen No.	Time	Temperature No.1 K	Temperature No. 2 K	Temperature No. 3 K	Average temperature K	Observed total elongation 10^{-3} cm/cm	Observed unit elongation 10^{-3} cm/cm	Unit elongation correction for dilatometer motion 10^{-3} cm/cm	Corrected specimen unit elongation 10^{-3} cm/cm
Specimen 6			Initial length: 7.6057 cm			Initial weight: - g			
Run 2			Final length: 7.4244 cm			Final weight: - g			
Density 0.255 gm/cm³									
Log 5184-102	3:30	298.3	298.3	298.3	298.3	0.00	0.00	0.00	0.00
	3:55	334.7	331.4	334.7	333.6	4.93	0.65	0.01	0.66
	4:06	345.0	341.5	345.8	344.1	3.71	0.49	0.01	0.50
	4:15	353.0	349.4	353.7	352.0	1.37	0.18	0.02	0.20
	4:35	368.9	364.4	369.4	367.6	-8.38	-1.10	0.02	-1.08
	5:05	411.1	405.3	411.7	409.3	-59.39	-7.81	0.04	-7.77
	5:36	457.0	450.0	457.0	454.7	-101.55	-13.35	0.06	-13.29
	6:19	496.0	490.5	496.4	494.3	-31.14	-17.24	0.08	-17.16
	8:00 am	298.3	298.3	298.3	298.3	-17.61	-23.15	0.00	-23.15

TABLE 16

THERMAL EXPANSION OF MG-36, SILICONE-PHENOLIC, IN THE Y DIRECTION
MEASURED IN QUARTZ DILATOMETER

Specimen	Time	Specimen temperatures - K				Observed total elongation 10^{-3} cm	Observed unit elongation 10^{-3} cm/cm	Unit elongation correction for dilatometer motion 10^{-3} cm/cm	Corrected specimen unit elongation 10^{-3} cm/cm
		Top	Middle	Bottom	Average				
Spec MG-36-QEXP-W-1 Run 5317-18-14 Density: 0.2259 gm/cm^3		Initial Length: 7.663 cm Final Length: 7.529 cm				Initial Weight: 3.4129 g Final Weight: 3.0975 g			
	10:45	297	297	297	297	0.00	0.00	0.00	0.00
	11:43	311	311	311	311	0.36	0.05	0.00	0.05
	12:40	366	366	366	366	1.07	0.14	0.02	0.16
	1:35	424	424	424	424	-8.26	-1.08	0.05	-1.03
	2:23	478	478	478	478	-80.44	-10.50	0.08	-10.42
	3:20	533	533	533	533	-108.86	-14.20	0.11	-14.09
	7:30	298	298	298	298	-180.34	-23.53	0.00	-23.53

TABLE 17

THE THERMAL EXPANSION OF SLA-561, FILLED CORK
MEASURED IN QUARTZ DILATOMETER

Specimen No.	Time	Temperature No. 1 K	Temperature No. 2 K	Temperature No. 3 K	Average temperature K	Observed total elongation 10^{-3}cm	Observed unit elongation 10^{-3}cm/cm	Unit elongation correction for dilatometer motion 10^{-3} cm/cm	Corrected specimen unit elongation 10^{-3} cm/cm
Specimen 5 Run 1 Density: 0.232 gm/cm^3 Initial length: 6.9545 cm Final length: 6.9049 cm Initial weight: 2.0148 g Final weight: 1.9523 g	9:30	298.9	298.9	298.9	298.9	0.00	0.00	0.00	0.00
	9:45	281.4	276.7	277.2	278.4	-6.30	-0.91	-0.01	-0.92
	10:00	256.7	251.9	250.3	253.0	-11.63	-1.67	-0.01	-1.68
	10:25	221.9	213.9	213.9	216.6	-22.02	-3.17	-0.01	-3.18
	11:30	180.0	177.8	176.1	178.0	-42.34	-6.09	0.00	-6.09
	12:25	150.0	146.7	142.2	146.3	-52.81	-7.60	0.01	-7.59
	12:50	184.4	181.1	176.1	180.6	-43.41	-6.24	0.00	-6.24
	1:10	229.4	232.8	231.1	231.1	-25.25	-3.63	0.01	-3.64
	1:30	265.0	266.1	265.0	265.4	-16.46	-2.37	-0.01	-2.38
	2:10	297.2	297.2	297.8	297.4	-9.04	-1.30	0.00	-1.30
	Hot Run								
	2:10	297.2	297.2	297.8	297.4	0.00	0.00	0.00	0.00
	3:00	314.4	314.4	313.9	314.3	0.00	0.00	0.00	0.00
	3:25	336.7	337.2	336.1	336.7	-4.06	-0.58	-0.01	-0.57
	4:05	370.6	371.7	367.8	370.0	-17.17	-2.47	-0.02	-2.45
	4:30	396.1	397.8	393.3	395.7	-24.49	-3.52	-0.03	-3.49
	5:00	424.4	427.2	422.2	424.6	-24.89	-3.58	-0.04	-3.54
	5:25	448.3	450.6	445.6	448.0	-23.04	-3.31	-0.06	-3.25
	6:00	476.7	479.4	473.3	476.5	-22.48	-3.23	-0.07	-3.16
	7:50 am	298.3	298.3	298.3	298.3	-50.67	-7.29	0.00	-7.29

TABLE 18

THE THERMAL EXPANSION OF SLA-561, FILLED CORK
MEASURED IN QUARTZ DILATOMETER

Specimen No.	Time	Temperature No. 1 K	Temperature No. 2 K	Temperature No. 3 K	Average temperature K	Observed total elongation 10^{-3} cm/cm	Observed unit elongation 10^{-3} cm/cm	Unit elongation correction for dilatometer motion 10^{-3} cm/cm	Corrected specimen unit elongation 10^{-3} cm/cm
Specimen 6	11:40	298.3	298.3	298.3	298.3	0.00	0.00	0.00	0.00
Run 1	12:15	279.4	277.8	277.8	278.3	-5.23	-0.75	-0.01	-0.76
Density: 0.227 gm/cm^3	12:40	250.0	246.1	246.7.	247.6	-15.98	-2.30	-0.01	-2.31
Initial length:	1:00	215.0	212.2	210.6	212.6	-27.28	-3.92	-0.01	-3.93
6.9575 cm	1:45	171.1	167.2	164.4	167.6	-41.88	-6.02	0.00	-6.02
Final length:	2:00	149.4	146.7	144.4	146.9	-48.49	-6.97	0.01	-6.96
6.8394 cm	2:40	190.0	188.9	187.8	188.9	-35.53	-5.11	-0.01	-5.12
Initial weight:	3:00	227.8	227.8	227.8	227.8	-23.04	-3.31	-0.02	-3.33
2.0135 g	3:30	255.6	255.6	255.6	255.6	-12.67	-1.82	-0.01	-1.83
Final weight:	4:35	299.4	299.4	299.4	299.4	-7.72	-1.11	0.00	-1.11
1.9200 g	Run 2,	Hot Run							
	4:35	299.4	299.4	299.4	299.4	0.00	0.00	0.00	0.00
	5:10	311.7	311.7	310.6	311.3	-4.95	-0.71	0.00	-0.71
	5:55	342.2	343.3	340.6	342.0	-15.75	-2.26	0.01	-2.25
	6:15	367.2	367.2	363.9	366.1	-24.13	-3.47	0.02	-3.45
	6:40	394.4	395.0	390.6	393.3	-32.51	-4.67	0.03	-4.64
	7:00	422.8	423.9	417.8	421.5	-31.62	-4.55	0.04	-4.51
	7:15	447.2	449.4	442.2	446.3	-27.56	-3.96	0.06	-3.90
	7:30	476.1	479.4	471.1	475.6	-23.95	-3.44	0.07	-3.37
	7:50	505.0	506.7	498.9	503.5	-29.10	-4.19	0.09	-4.10
	7:30am	297.8	297.8	297.8	297.8	-93.73	-13.47	0.00	-13.47

TABLE 19

THERMAL EXPANSION OF SLA-561, FILLED CORK MEASURED IN QUARTZ DILATOMETER

Specimen	Time	Specimen temperatures - K				Observed total elongation 10^{-3} cm	Observed unit elongation 10^{-3} cm/cm	Unit elongation corrected for dilatometer motion 10^{-3} cm/cm	Corrected specimen unit elongation 10^{-3} cm/cm
		Top	Middle	Bottom	Average				
Specimen 7 Run 5317-38-14 Density: 0.2210 gm/cm^3		Initial Length: 7.620 cm Final Length: 7.445 cm				Initial Weight: 2.1628 g Final Weight: 2.0271 g			
	12:26	298	298	298	298	0.00	0.00	0.00	0.00
	1:20	339	339	339	339	-11.05	-1.45	0.01	-1.32
	1:51	366	366	367	366	-24.36	-3.20	0.02	-3.17
	2:30	422	423	423	423	-31.83	-4.18	0.05	-4.13
	3:00	491	492	492	492	-33.71	-4.42	0.08	-4.34
	3:25	532	533	534	533	-66.04	-8.67	0.11	-8.56
	8:58	300	300	300	300	-159.51	-20.93	0.00	-20.93

TABLE 20

THERMAL EXPANSION OF SLA-561, FILLED CORK, IN THE Y DIRECTION
MEASURED IN QUARTZ DILATOMETER

Specimen	Time	Specimen temperatures - K				Observed total elongation 10^{-3}cm	Observed unit elongation 10^{-3}cm/cm	Unit elongation corrected for dilatometer motion 10^{-3}cm/cm	Corrected specimen unit elongation 10^{-3}cm/cm
		Top	Middle	Bottom	Average				
Spec SLA-561-QEXP W-1 Run 5317-19-15 Density: 0.2016 gm/cm^3		Initial Length: 7.653 cm Final Length: 7.556 cm				Initial Weight: 3.0417 g Final Weight: 2.8650 g			
	10:35	298	298	298	298	0.00	0.00	0.00	0.00
	11:40	311	311	311	311	1.12	0.15	0.00	0.15
	12:45	367	367	368	367	-0.15	-0.02	0.02	0.00
	1:30	422	422	422	422	-0.08	-0.01	0.05	0.04
	2:20	478	478	478	478	0.15	0.02	0.07	0.09
	3:10	532	533	533	533	-10.31	-1.35	0.10	-1.24
	7:30	298	298	298	298	-65.84	-8.60	0.00	-8.60

TABLE 21

SUMMARY OF DATA ON ABLATORS EVALUATED UNDER SUBTASK A

Material	Material description	Identification	Bulk density gm/cm^3	Temp. K	Thermal conductivity W/m-K	Temp. K	Heat capacity Joules/Kg-K	Thermal diffusivity cm^2/sec
1	50% RTV-602, 20% powdered phenolic, 25% phenolic spheres, 5% dimethyl oil (percents by weight)	E6A7, Billet 6A to E6A7, Billet 8A	0.651 to 0.653	349 342	0.106 0.105	300	1440	1.12×10^{-3}
2	Silicone elastomer with carbon black filler in phenolic-glass honeycomb	Type S-20T	0.329 to 0.356	344 338	0.080 0.077	300	1330	1.72×10^{-3}
3	25% silicone resin, 71% phenolic microballons, 4% quartz fibers (percents by weight)	MG-36	0.251 to 0.258	350 350	0.058 0.063	300	1420	1.67×10^{-3}
4	Filled cork, composition proprietary	SLA-561	0.222 to 0.232	350 350	0.057 0.061	300	1290	2.01×10^{-3}

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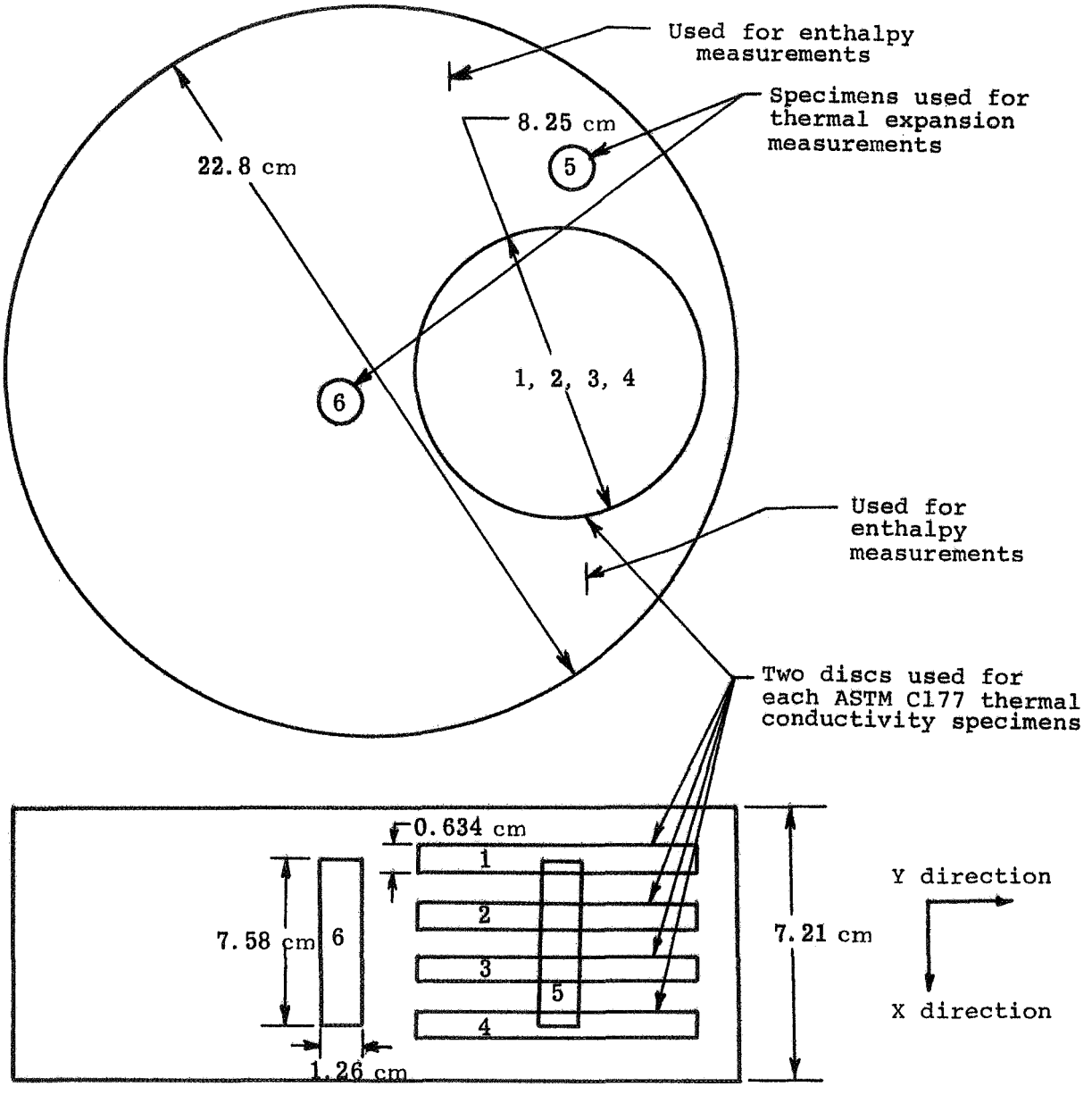


Figure 2. Cutting plan for thermal conductivity and thermal expansion specimens for MG-36, Silicone-Phenolic

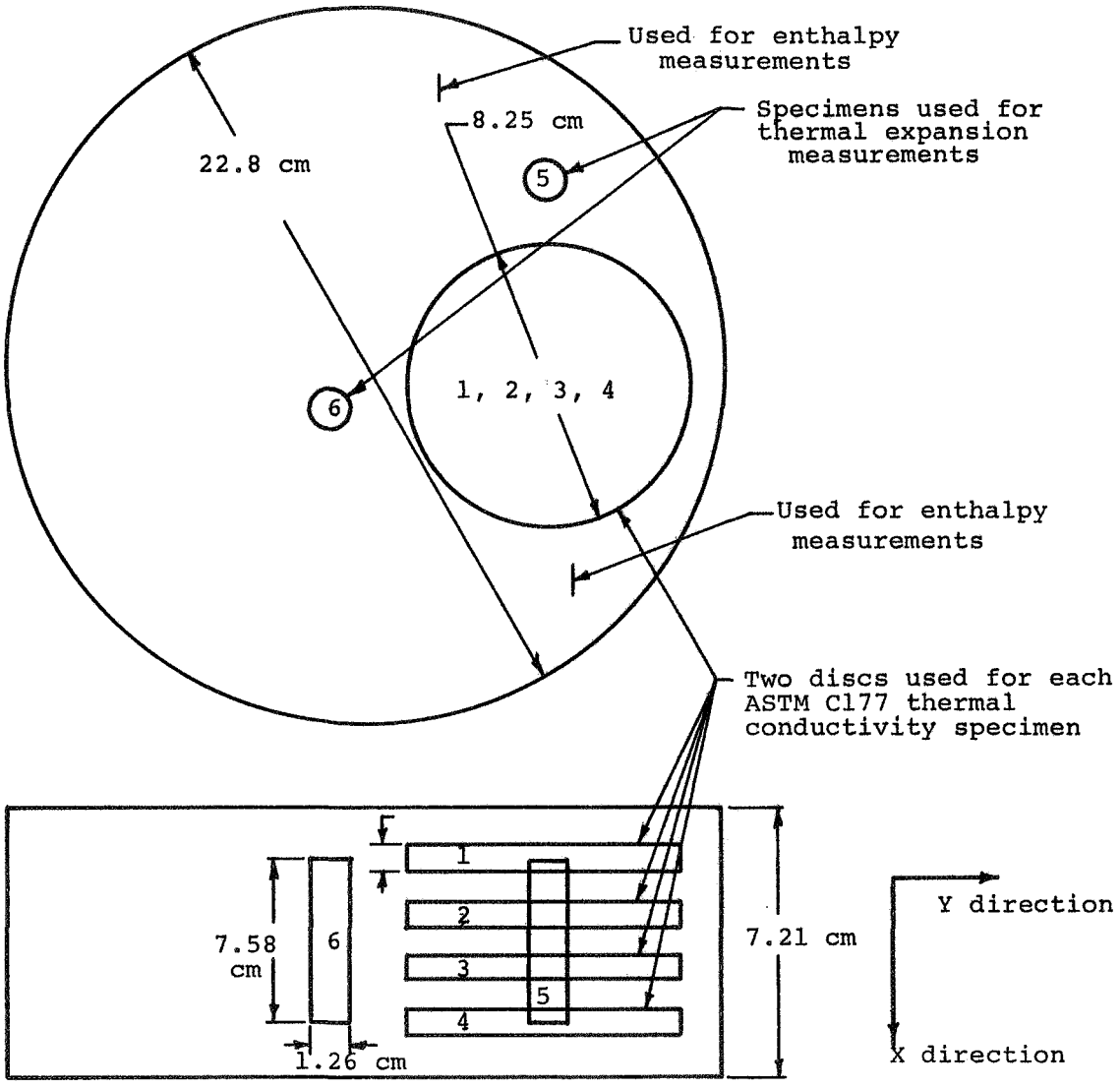


Figure 3. Cutting plan for thermal conductivity and thermal expansion specimens for SLA-561, Filled Cork

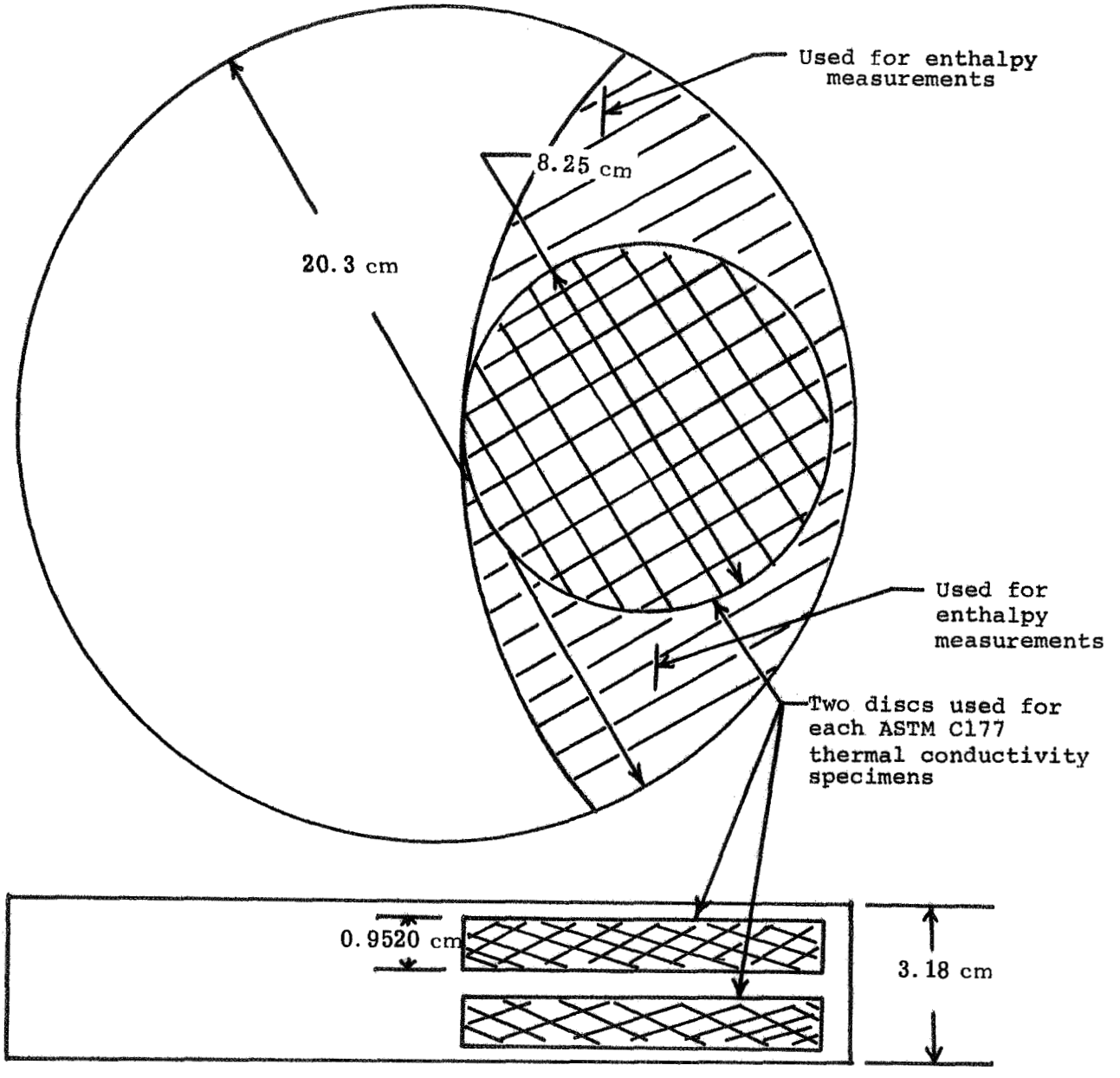


Figure 4. Cutting plan for thermal conductivity specimens from Billets 6A and 8A of E6A7, Silicone-Phenolic

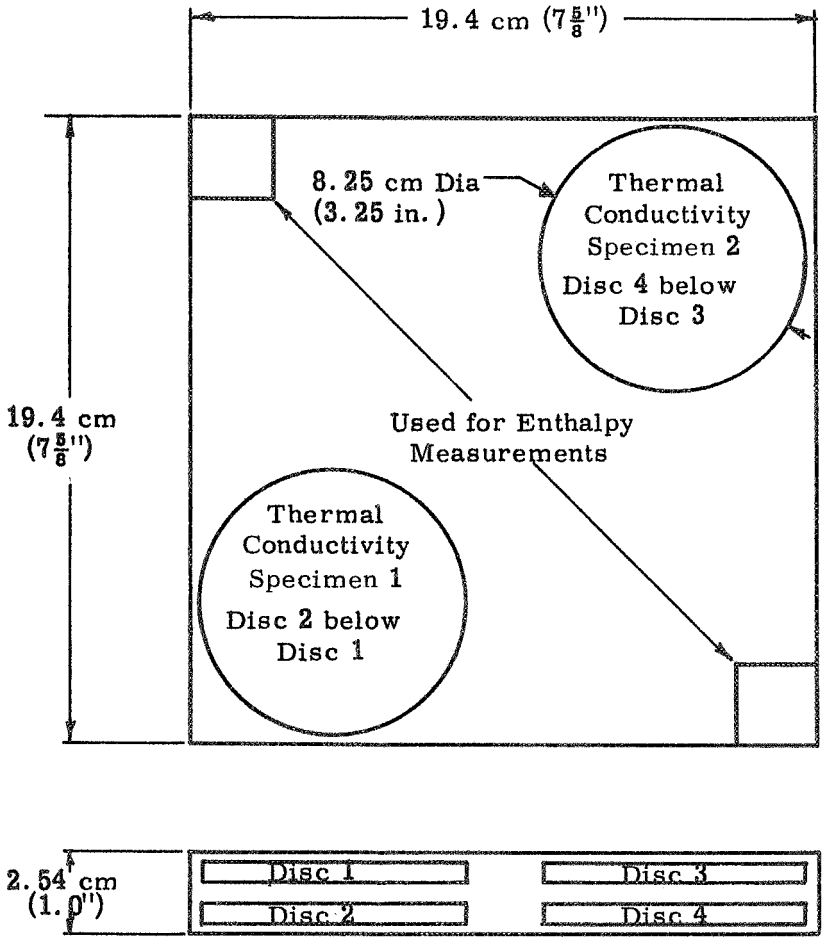
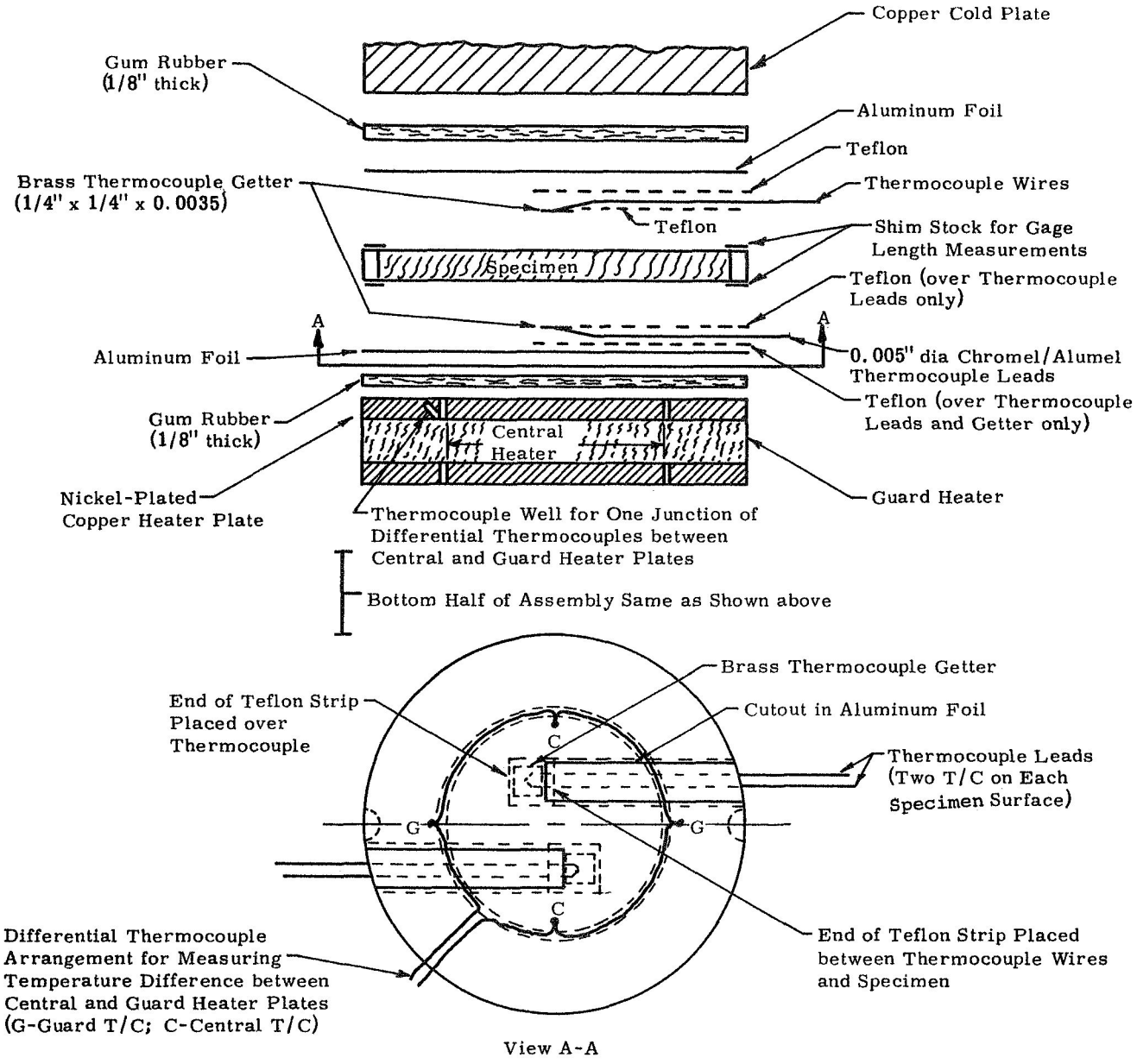


Figure 5. Cutting plan for thermal conductivity specimen for ASTM apparatus from Virgin S-20T, Blown Silicone-Elastomer with carbon black filler in phenolic-glass honeycomb



Notes:

1. Buildup shown is used from 150 to 300K.
2. Between 300 and 400K, gum rubber on hot surface of specimen is replaced by two Fiberfrax discs each 0.318 cm thick and a Fiberfrax disc of the same thickness is placed between the gum rubber and the specimen on the cold surface.
3. Above 400K, the same buildup as (2) above is used except that an asbestos disc 1.27 cm thick is placed between the gum rubber and Fiberfrax at the cold surface.

Figure 6. Schematic of buildup used for ASTM C177 guarded hot plate thermal conductivity apparatus

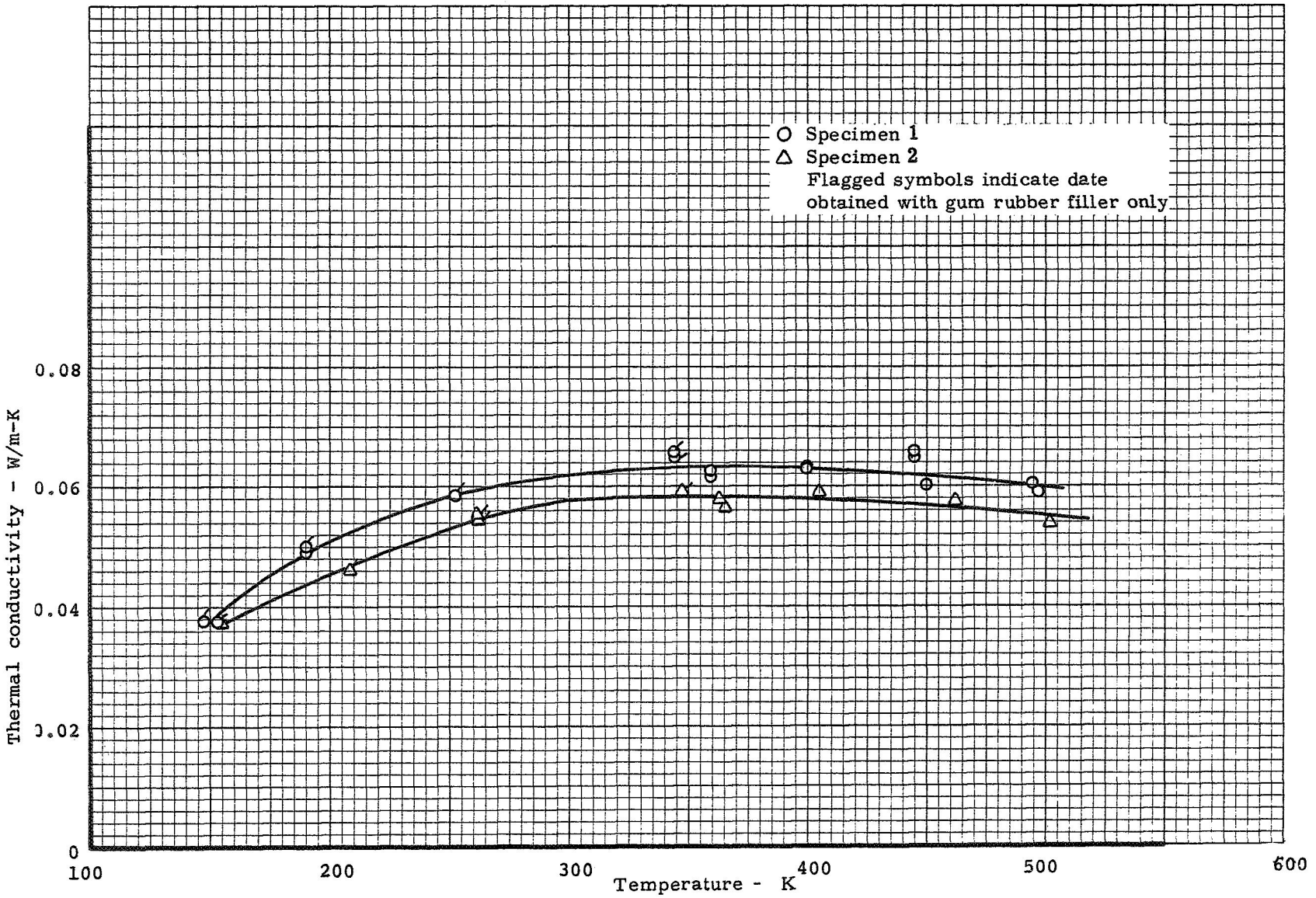


Figure 7. Thermal conductivity of MG-36, Silicone-Phenolic

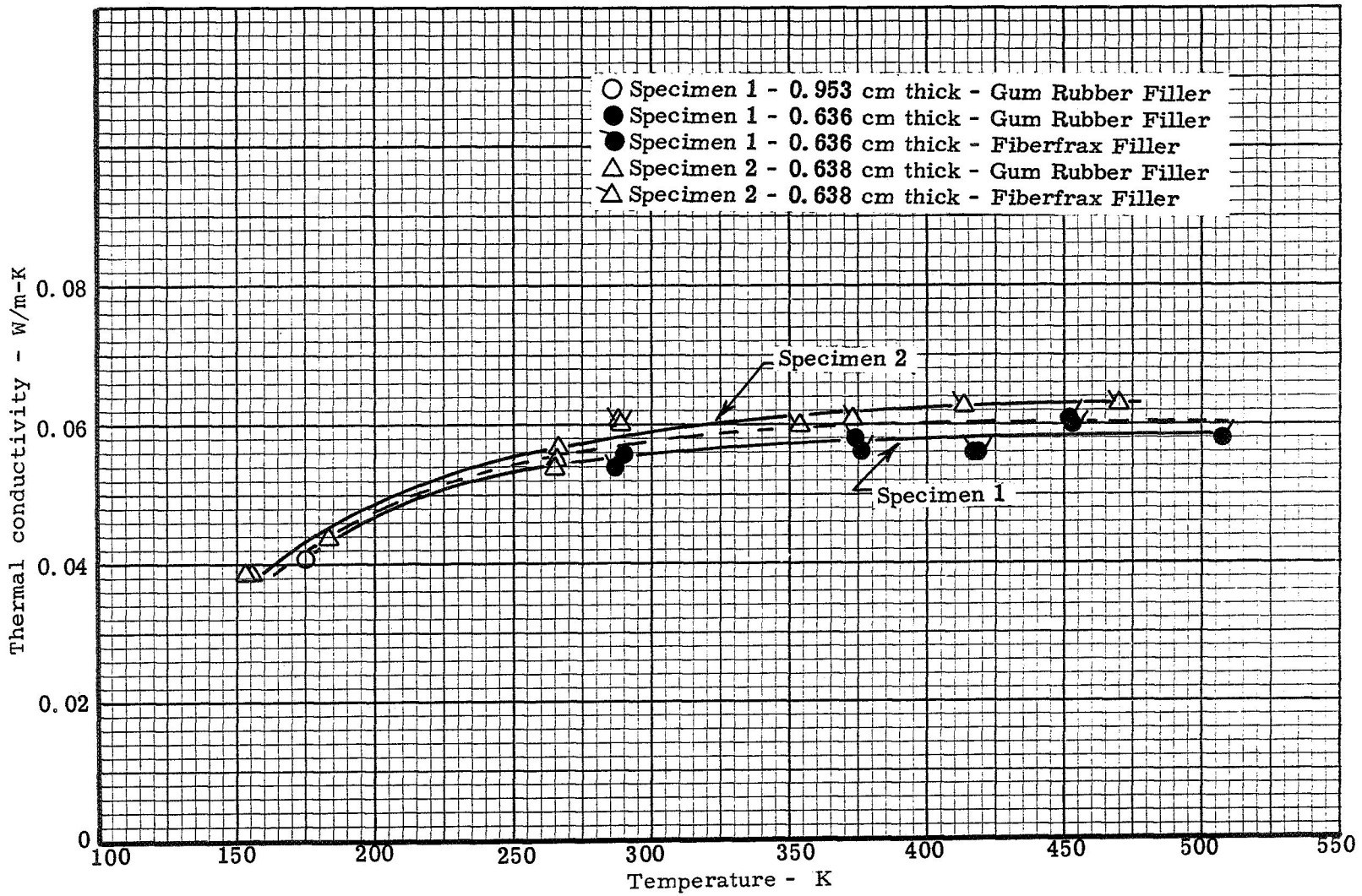


Figure 8. Thermal conductivity of SLA-561, Filled Cork

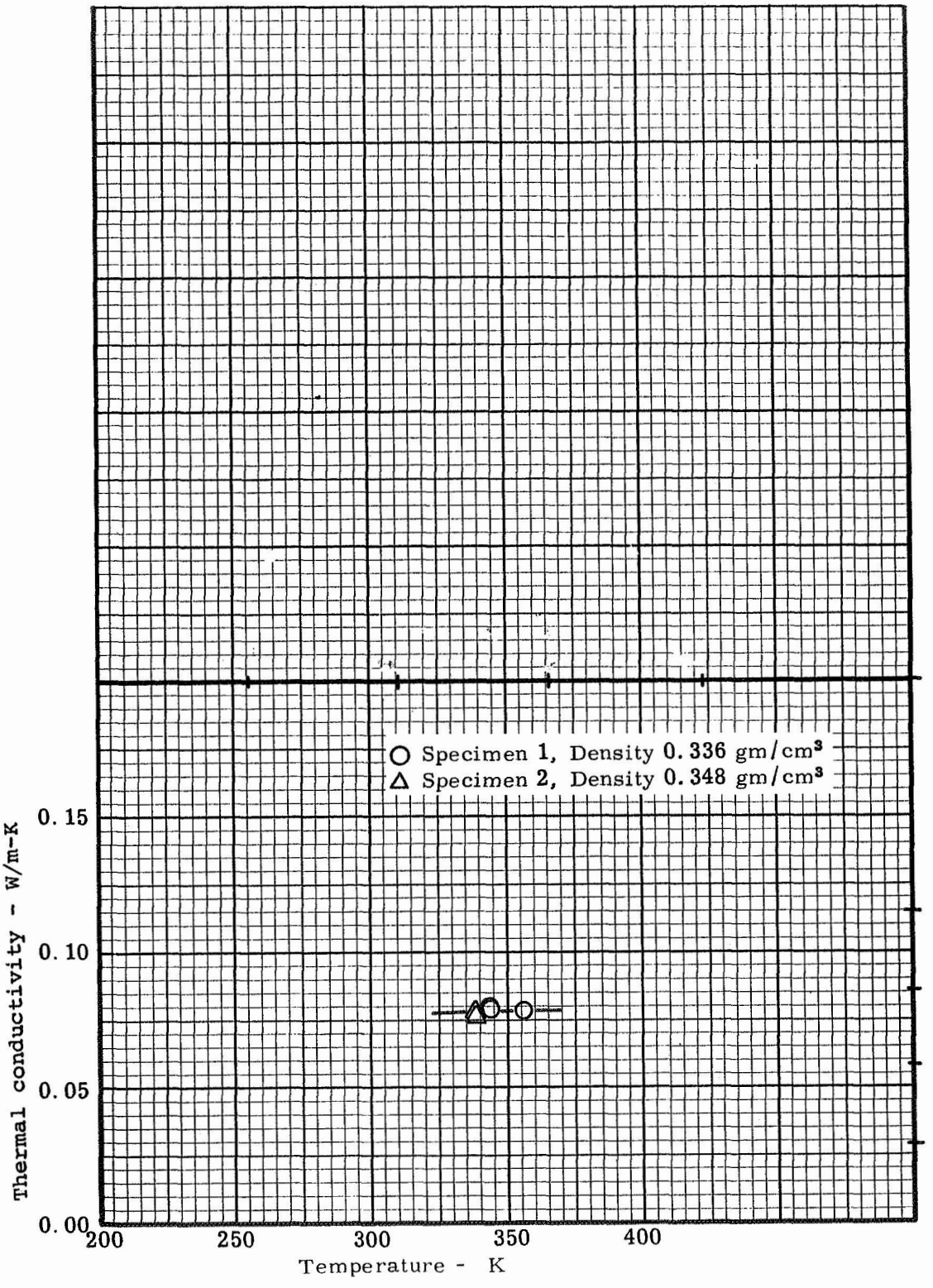


Figure 9. Thermal conductivity of Virgin S-20T, Blown Silicone Elastomer with carbon black filler in phenolic-glass honeycomb

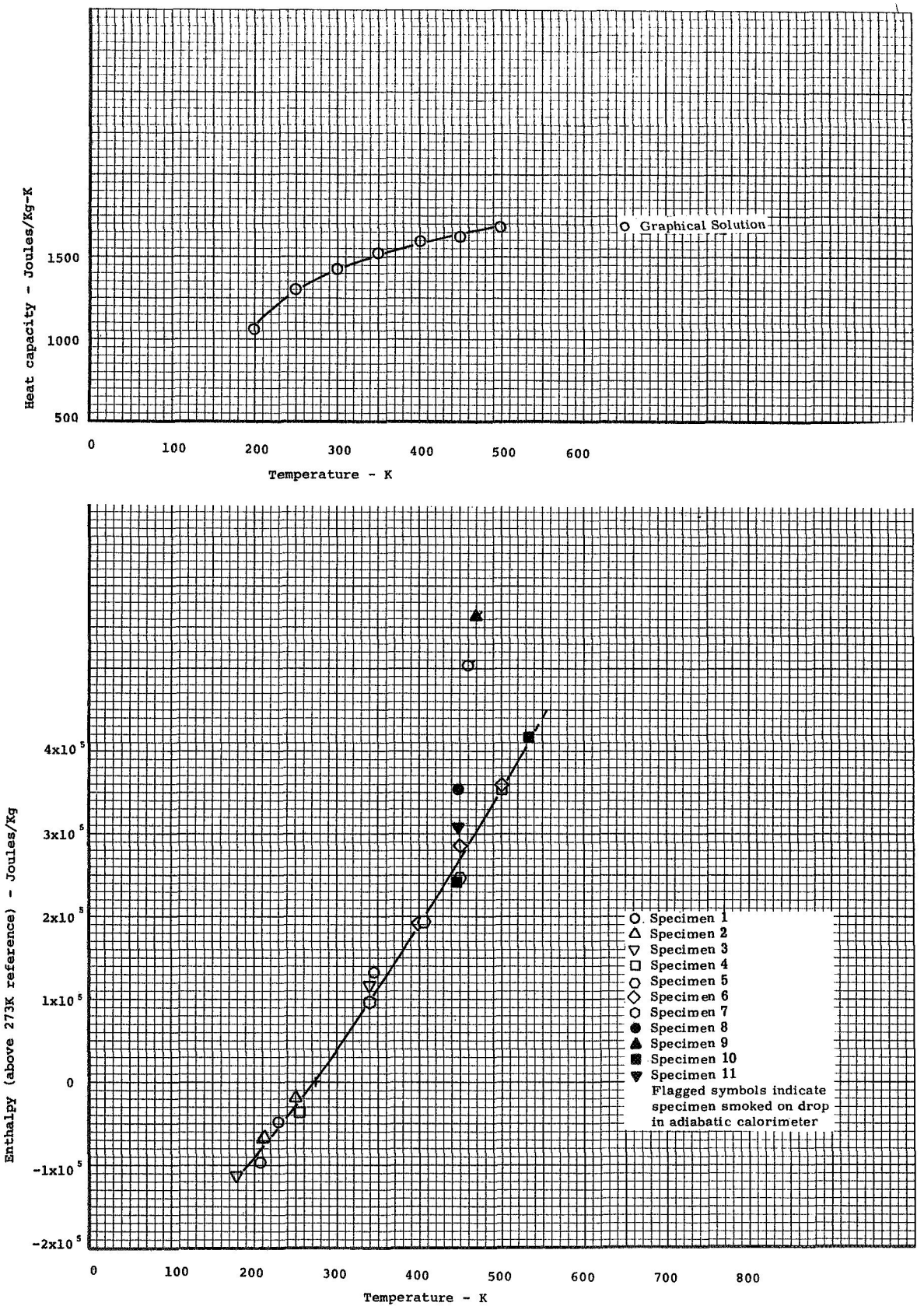
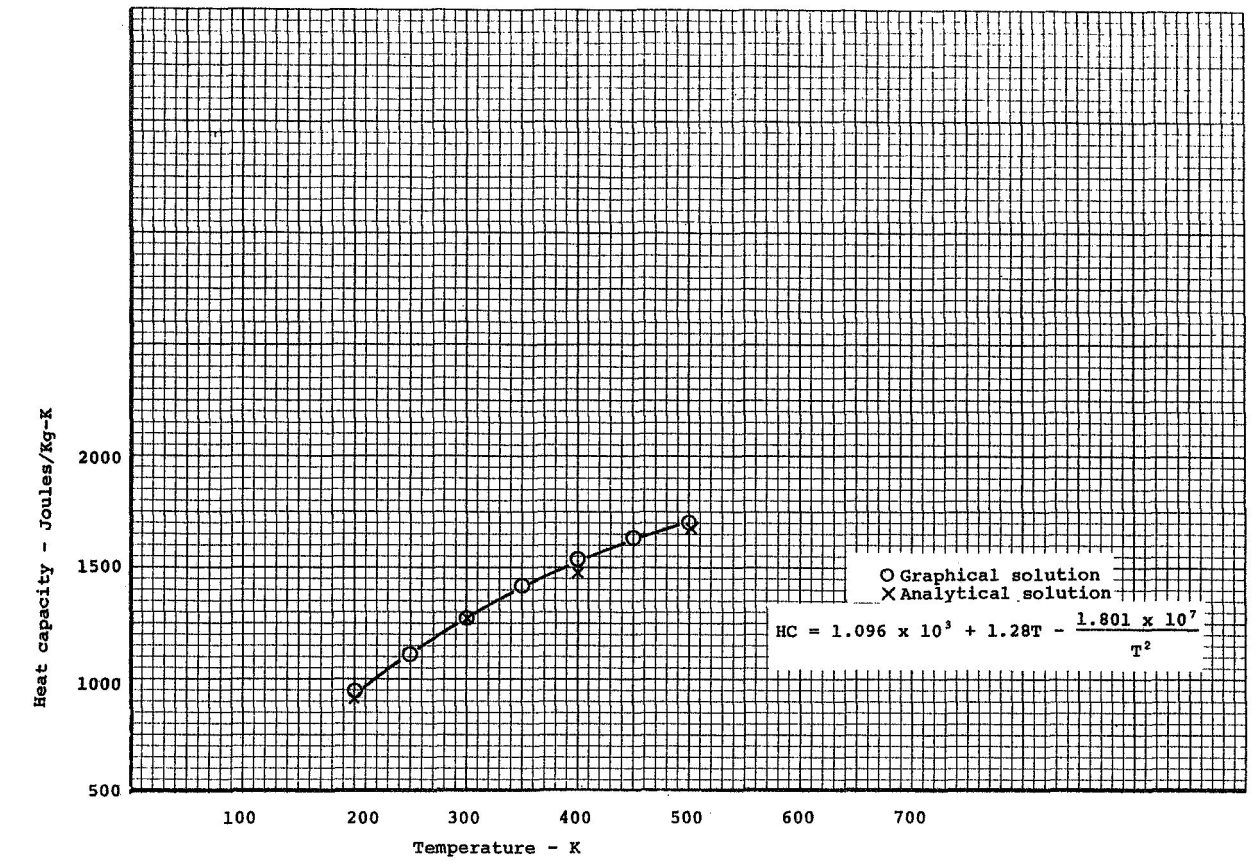


Figure 10. Enthalpy and heat capacity of MG-36, Silicone-Phenolic



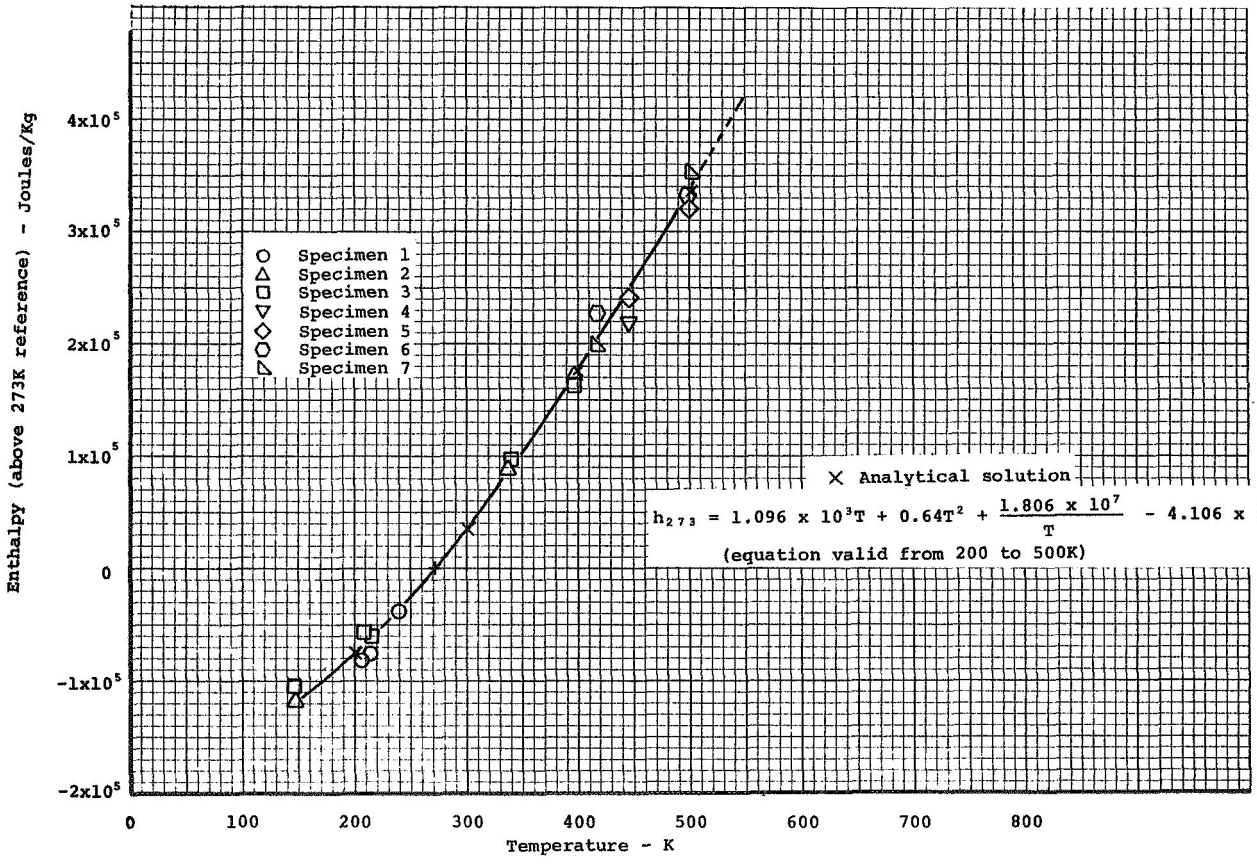


Figure 11. Enthalpy and heat capacity of SLA-561, Filled Cork

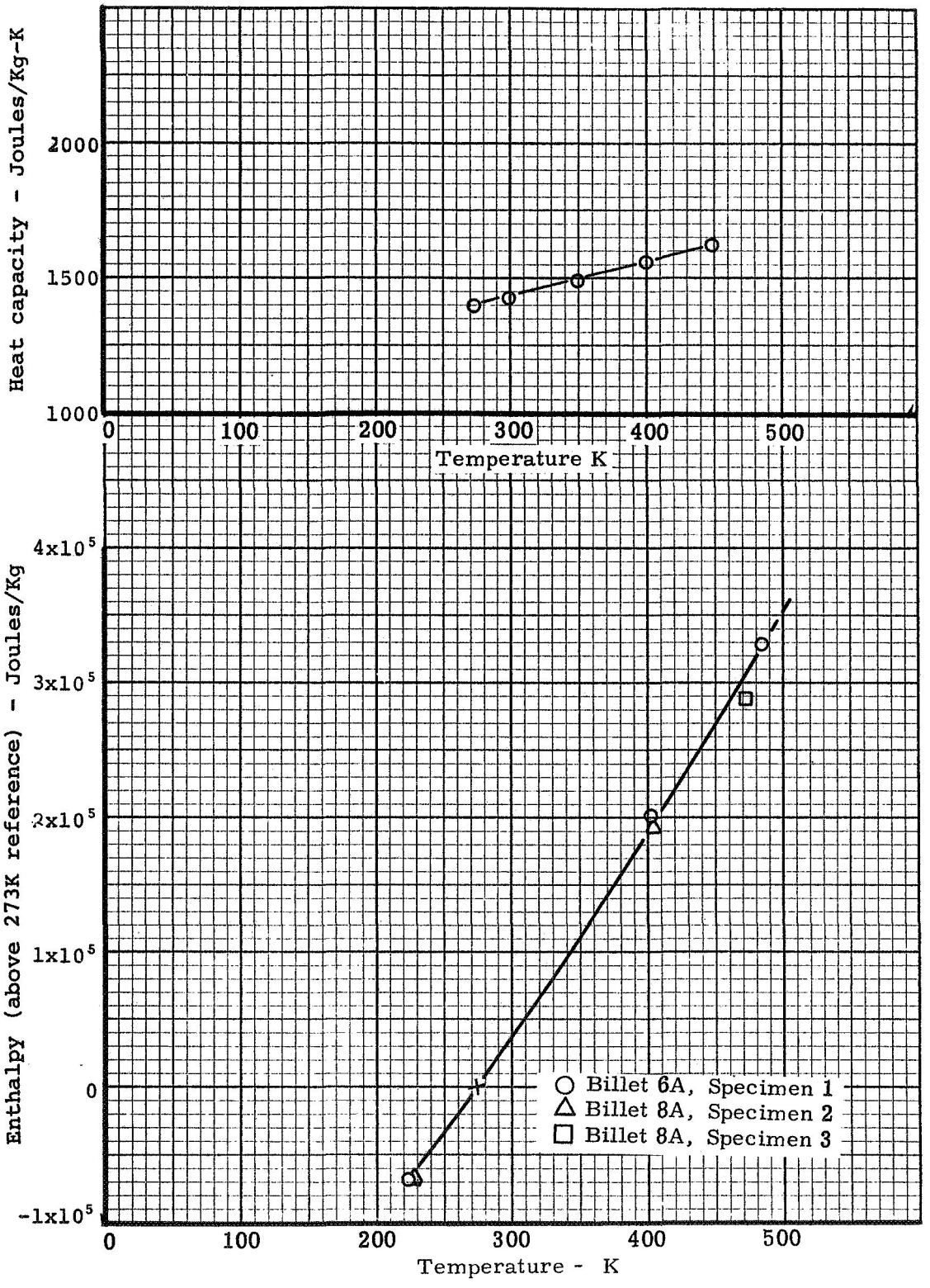


Figure 12. Enthalpy of Billets 6A and 8A of E6A7, Silicone-Phenolic

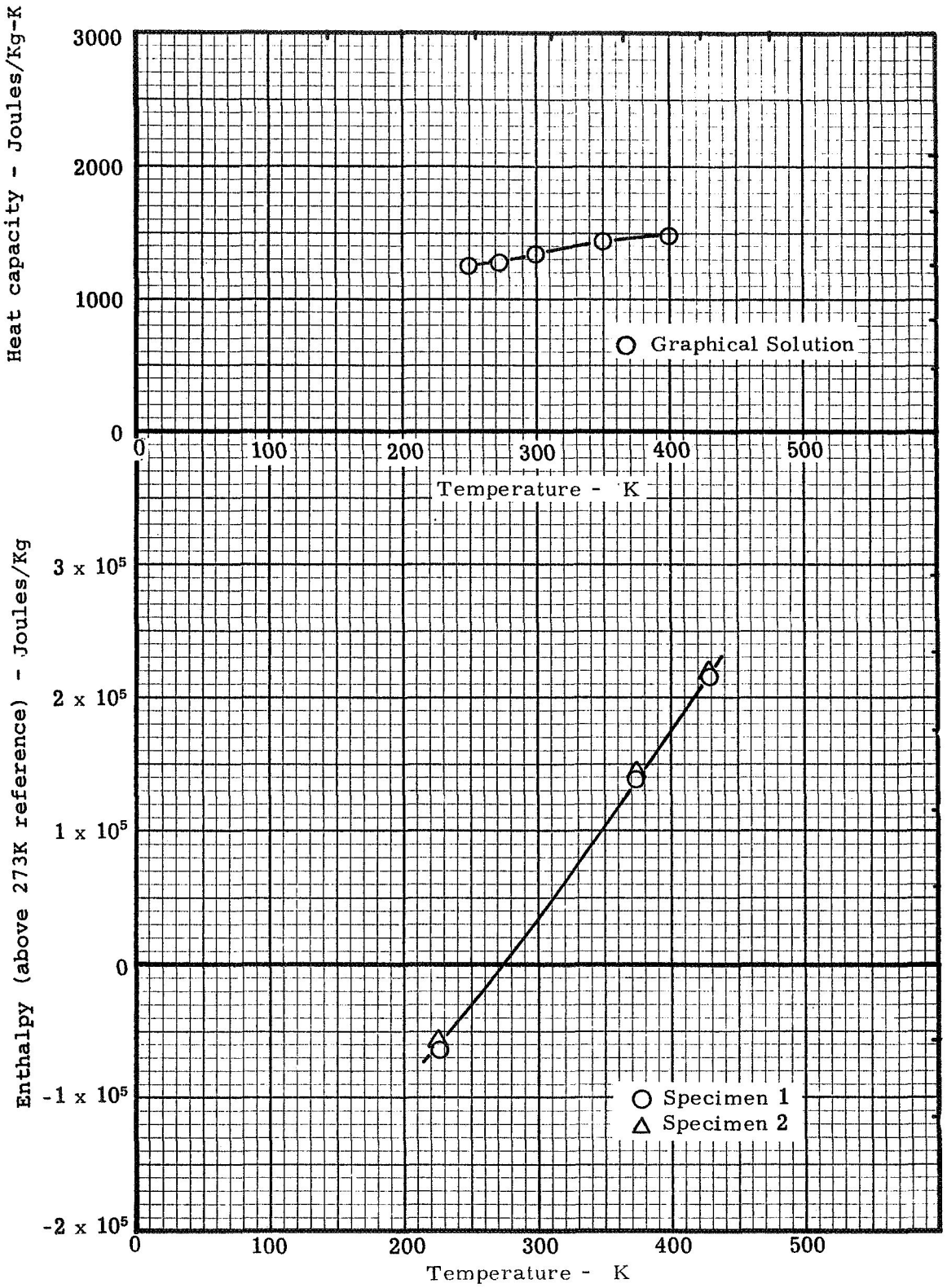


Figure 13. Enthalpy and heat capacity of Virgin S-20T, Blown Silicone Elastomer with carbon black filler in phenolic-glass honeycomb

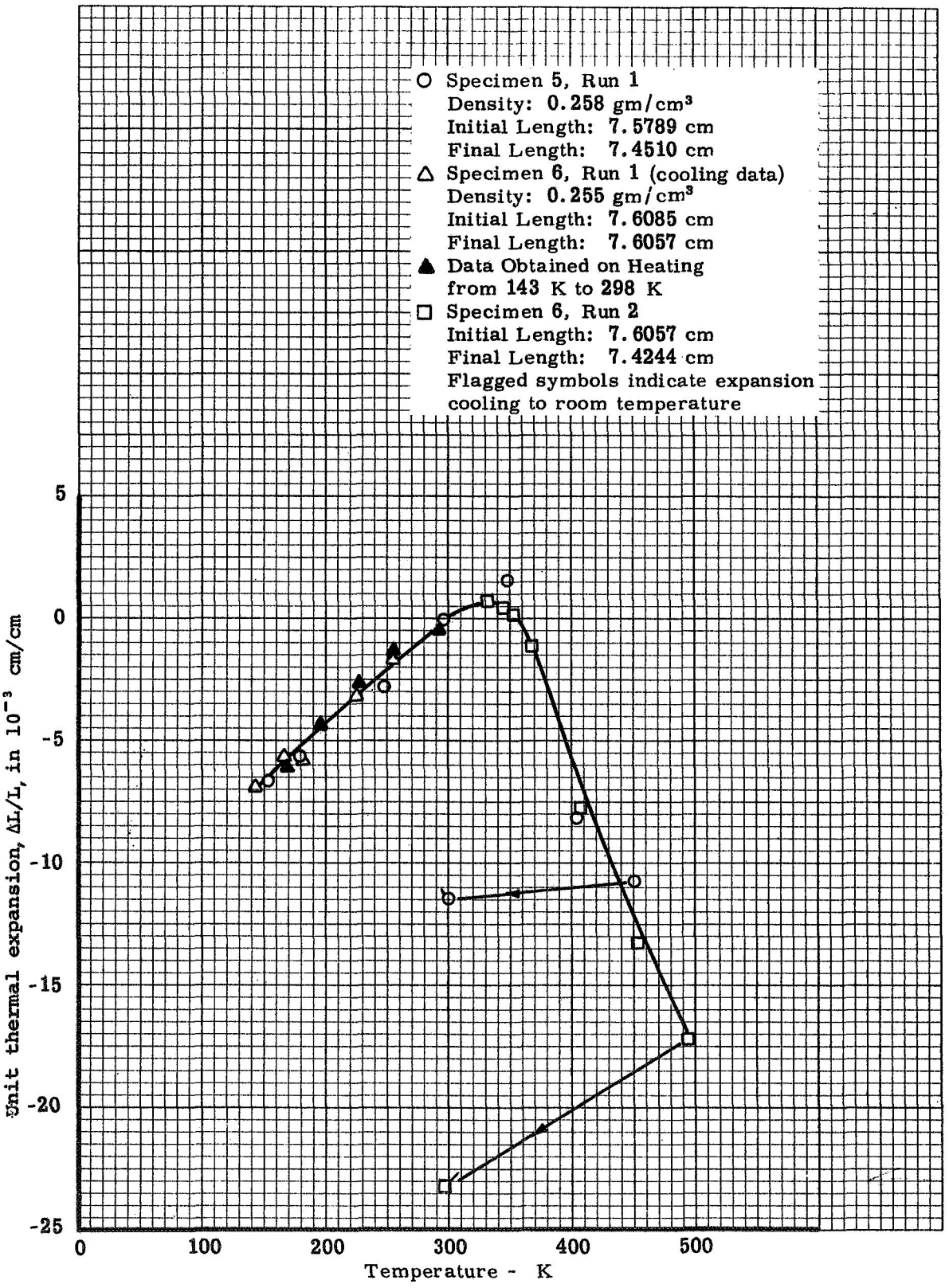


Figure 14. Thermal expansion of MG-36, Silicone-Phenolic, in the X direction

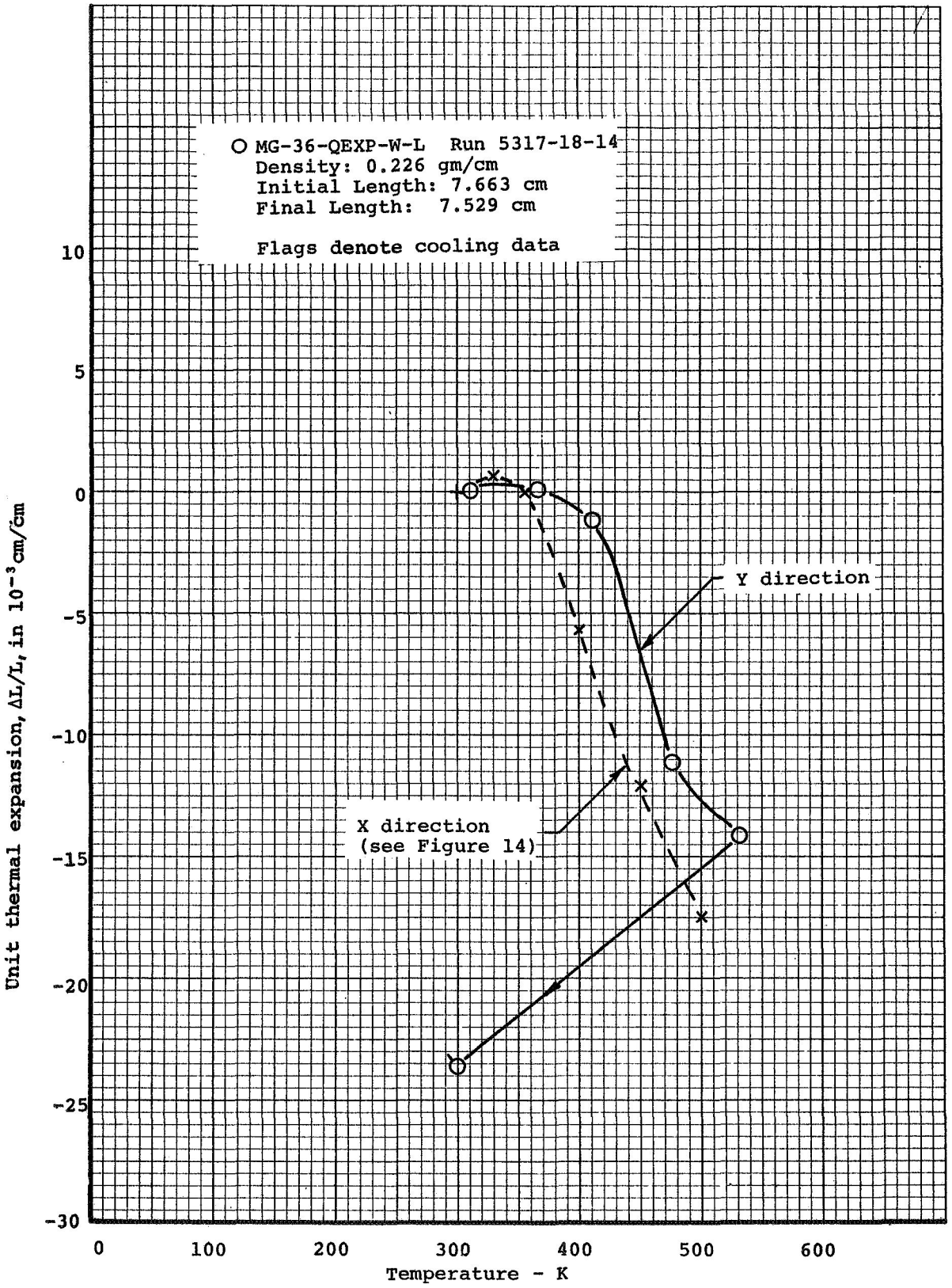


Figure 15. Thermal expansion of MG-36, Silicone-Phenolic, in the Y direction

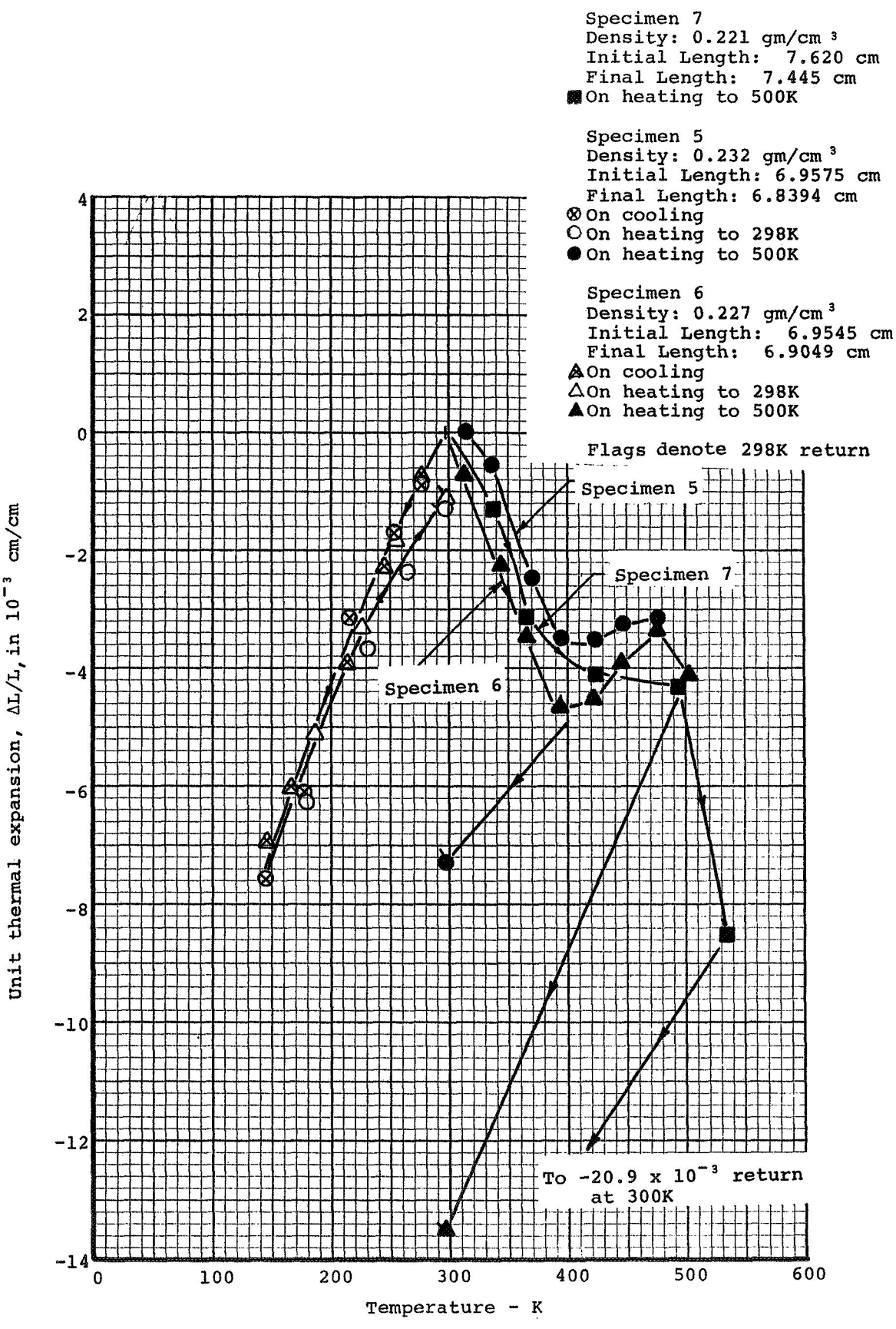


Figure 16. Thermal expansion of SLA-561, Filled Cork

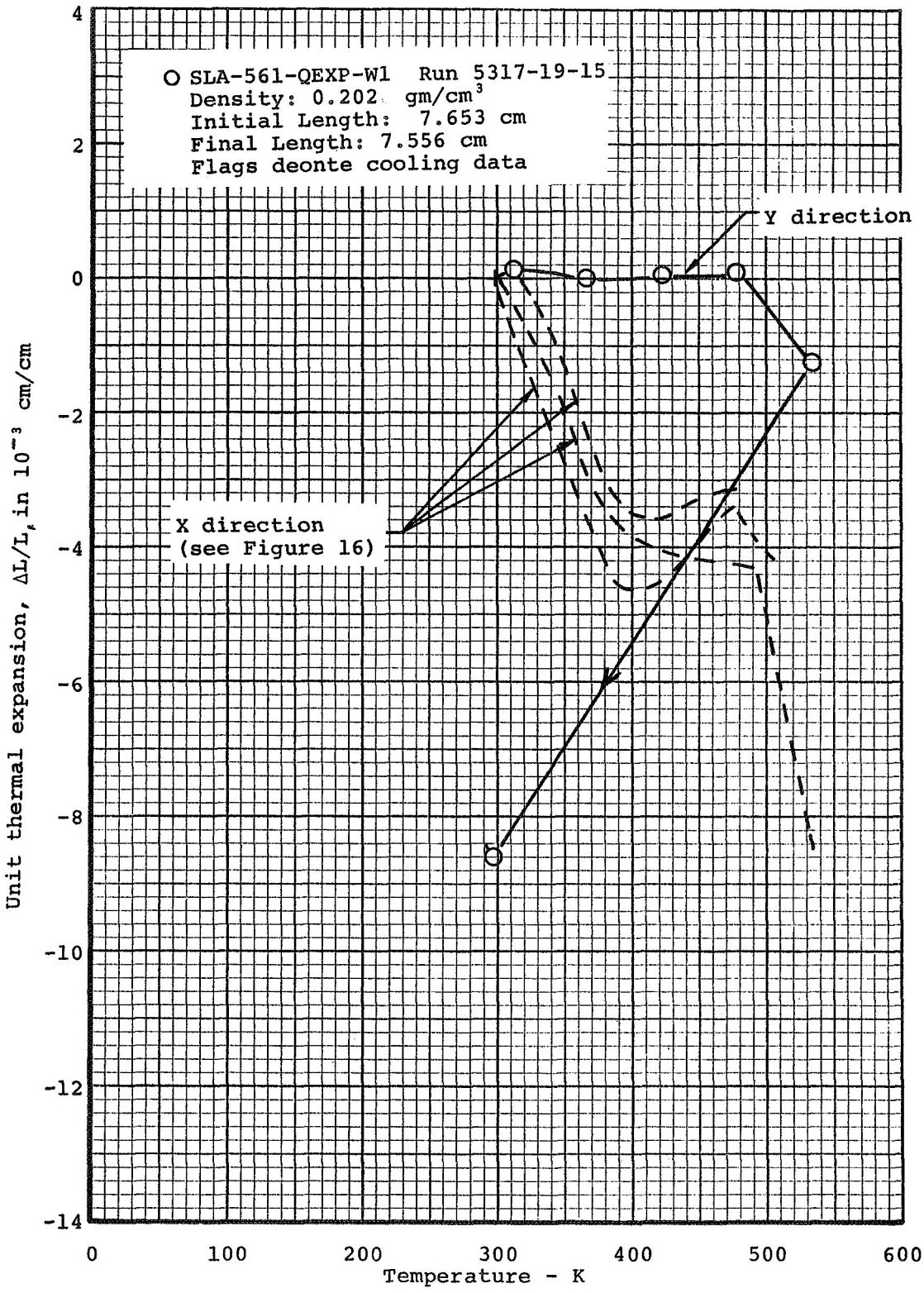


Figure 17. Thermal expansion of SLA-561, Filled Cork, in the Y Direction

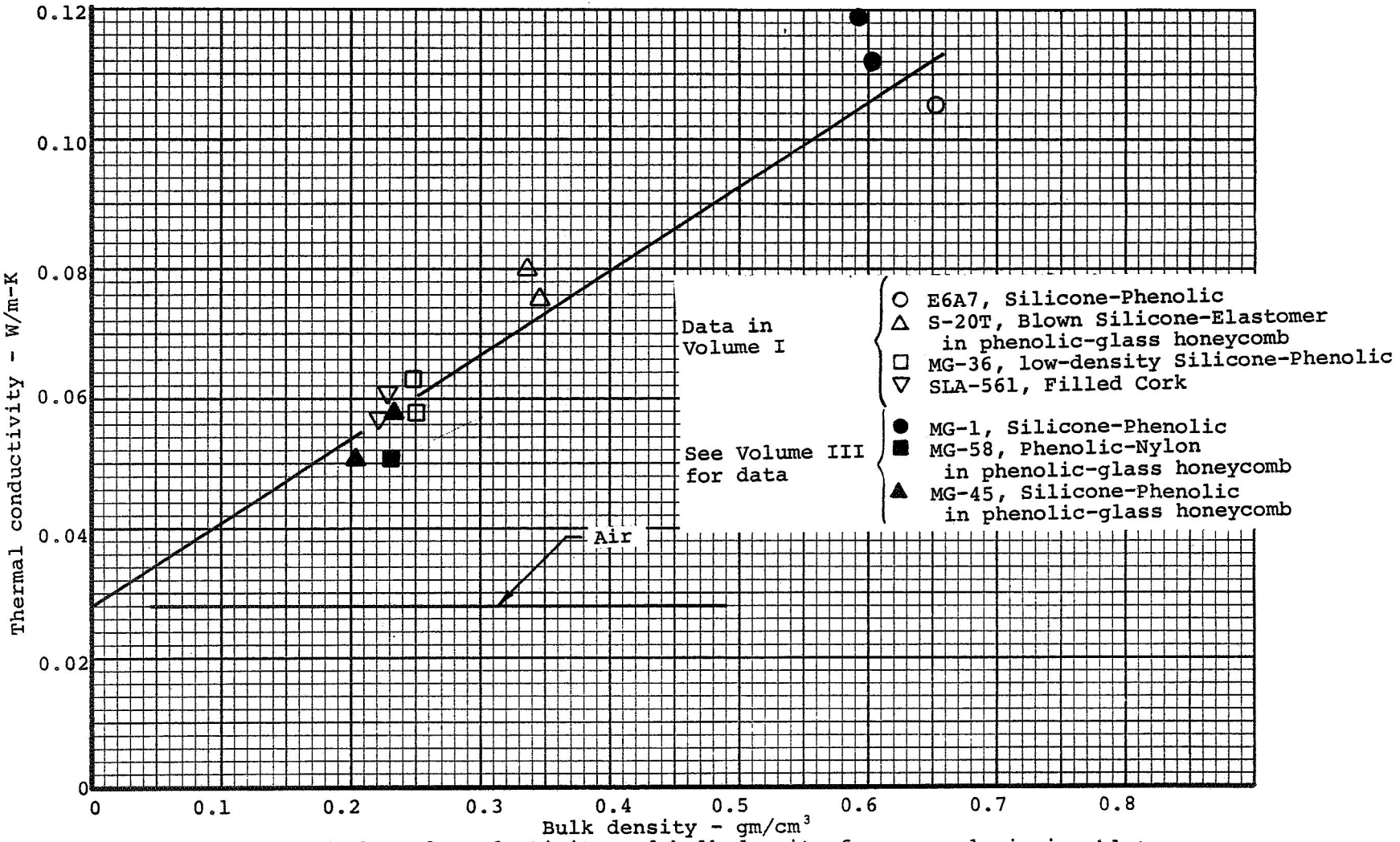


Figure 18. Plot of thermal conductivity and bulk density for several virgin ablators (at 340K)